Bacterial Total Maximum Daily Load Development for the James River and Tributaries – City of Richmond

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Prepared for:

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Background and Applicable Standards

The James River (H39R-08) and the tidally influenced section of the James River (G01E-01) were initially listed in 1996 for violations of the fecal coliform (FC) standard. Almond Creek was first listed on the *1998 303(d) Total Maximum Daily Load Priority List and Report* for fecal coliform standard violations. The Falling Creek, Goode Creek, Powhite Creek and Reedy Creek segments were placed on the *Virginia 2002 Section 303(d) Report on Impaired Waters* for violations of the fecal coliform standards. Bernards Creek, Gillie Creek, James River H39R-11, and No Name Creek were added to the *Virginia 2004 Section 305(b)/303(d) Water Quality Assessment Integrated Report*. Elevated levels of fecal coliform bacteria recorded at VADEQ ambient water quality monitoring stations showed that these James River stream segments do not support the primary contact recreation use. This study area combines rural, residential, and urban land uses, with potential bacteria sources from pets, livestock, wildlife and humans.

TMDL Endpoint and Water Quality Assessment

Potential sources of fecal coliform include both point source and nonpoint source (NPS) contributions. Nonpoint sources include: wildlife, grazing livestock, land application of manure and biosolids, urban/residential runoff, failed and malfunctioning septic systems, illicit cross-connections of residential wastes to the stormwater collection system, leaking sewer lines, and uncontrolled discharges (straight pipes), and non-permitted sewer overflows. When properly treated and applied to the land, biosolids are not a significant source of bacteria to waterbodies. Permitted sources include: permitted waste treatment facilities, domestic waste treatment systems, Combined Sewer Overflows (CSOs), and Municipal Separate Storm Sewer Systems (MS4s). There are currently 12 active permitted point sources in the watershed that are permitted for bacterial discharge. In addition, there are 13 single-family general wastewater permits in the watershed. These discharges are small (<1,000 g/day) and are expected to meet the *E. coli* standard. MS4 areas that drain to the James River – City of Richmond watersheds include portions of the

City of Richmond, Henrico County, Chesterfield County, VDOT drainages, as well as 3 smaller permitted areas.

Fecal bacteria TMDLs in the Commonwealth of Virginia are developed using the *E. coli* standard. For this TMDL development, the in-stream *E. coli* target was a geometric mean not exceeding 126 colony-forming units per 100 milliliters of water sampled (cfu/100 mL). A translator developed by VADEQ was used to convert fecal coliform values to *E. coli* values.

Modeling Procedures

Hydrology

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to model hydrology and fecal coliform loads in the riverine segments. CE-QUAL-W2 (Army Corps of Engineers, 2003) meets the requirements of modeling the tidal portion of this system, including: time varying point and non-point sources, wind, tides, a first order decay-based general quality constituent component and continuous simulation.

For purposes of modeling inputs to streamflow and in-stream fecal bacteria in the James River – City of Richmond watershed, the drainage area was divided into 67 subwatersheds, with multiple segments per subwatershed (branch) in the CE-QUAL-W2 model.

Hydrologic calibration was conducted during the development of Total Maximum Daily Load Development for the James River and Tributaries – Lower Piedmont Region (VADEQ, 2007a) and Total Maximum Daily Load Development for the Upham Brook watershed (VADEQ, 2007b). The model was calibrated for hydrologic accuracy using daily flow data from USGS Gaging Station 02037500 on the James River for the period October 2000 through September 2003 for the James River and Tributaries – Lower Piedmont Region. The calibration of stream flow in Upham Brook was performed using daily flow data from USGS Gaging Station 02042426 on the Upham Brook for the period October 1991 through September 1994. The changes made to the hydrologic parameters of the rural land uses in the James River and Tributaries – Lower Piedmont Region were the same percent changes made to the hydrologic parameters of the rural land uses in James River – City of Richmond. The same principles were followed when using the changes to the urban land uses from the Upham Brook watershed.

Fecal Coliform

Wildlife populations, the rate of failure of septic systems, domestic pet populations, and numbers of livestock are examples of land-based nonpoint sources used to calculate fecal coliform loads. Also represented in the model were direct nonpoint sources of uncontrolled discharges, direct deposition by wildlife, direct deposition by livestock, and direct inputs from combined sewer overflows. Contributions from all of these sources were updated to current conditions to establish existing conditions for the watershed.

The fecal coliform calibration was conducted using data collected at VADEQ monitoring stations. For HSPF, a water quality calibration period of 10/1/1999 through 9/30/2003 was used in the model; the validation period was 10/1/2003 to 12/31/2006. The CE-QUAL-W2 model was run from 10/6/1999 through 10/5/2000 for calibration of the tidal segment of the James River. Both models provided a comparable match to the VADEQ monitoring data, with output from the model indicating violations of both the instantaneous and geometric mean standards throughout the impaired watersheds.

Load Allocation Scenarios

The next step in the bacteria TMDL process was to reduce the various source loads to levels that would result in attainment of the water quality standard. Because Virginia's *E. coli* standard does not permit any exceedances of the standard, modeling was conducted for a target value of 0% exceedance of the geometric mean standard. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. The final TMDL information is shown in Table ES.1. The final reductions scenarios are shown in Table ES.2. Alternative E refers to the preferred implementation of the City of Richmond's Phase III Combined Sewer Overflow (CSO) Control Plan (Greeley and Hanson, 2006 and Appendix E, Figure E.1).

Table ES.1 Average annual in-stream cumulative E. coli loads (cfu/year) modeled after allocation in the James River – City of Richmond impairments.

Impairment	WLA[1]	LA	MOS	TMDL	Existing Load	Percent Reduction
Almond Creek	**4.39E+12**	**2.28E+12**	Implicit	**6.67E+12**	**1.99E+13**	**66.5%**
VAG404029 [1]	*1.74E+09*					
MS4 City of Richmond *MS4 VDOT* [2]	*6.44E+10*					
MS4 Henrico County *MS4 VDOT* [2]	*1.18E+12*					
VA0063177: CSOs [3]	*3.08E+12*					
Future Load [4]	*6.67E+10*					
Bernards Creek	**1.67E+12**	**1.65E+14**		**1.67E+14**	**3.64E+14**	**54.1%**
Future Load [4]	*1.67E+12*					
Falling Creek	**1.64E+13**	**7.92E+13**		**9.56E+13**	**1.24E+14**	**22.8%**
VAG404238 [1]	*1.74E+09*					
MS4 Defense Supply Center – Richmond [2]	*5.60E+10*					
MS4 City of Richmond *MS4 VDOT* [2]	*1.79E+12*					
MS4 Chesterfield County *MS4 VDOT* [2]	*1.36E+13*					
Future Load [4]	*9.56E+11*					
Gillie Creek	**2.93E+12**	**3.36E+12**		**6.29E+12**	**8.71E+13**	**92.8%**
MS4 City of Richmond *MS4 VDOT* [2]	*6.28E+10*					
MS4 Henrico County *MS4 VDOT* [2]	*5.78E+11*					
VA0063177: CSOs [3]	*2.23E+12*					
Future Load [4]	*6.29E+10*					
Goode Creek	**2.52E+12**	**3.10E+12**		**5.62E+12**	**7.42E+13**	**92.4%**
MS4 City of Richmond *MS4 VDOT* [2]	*2.27E+12*					
MS4 McGuire Hospital [2]	*1.98E+11*					
Future Load [4]	*5.62E+10*					

Table ES.1 Average annual in-stream cumulative *E. coli* loads (cfu/year) modeled after allocation in the James River – City of Richmond impairments (continued).

Impairment	WLA[1]	LA	MOS	TMDL	Existing Load	Percent Reduction
NoName Creek	**4.66E+11**	**1.15E+12**		**1.61E+12**	**1.21E+13**	**86.7%**
MS4 Defense Supply Center – Richmond [2]	*1.23E+11*					
MS4 Chesterfield County *MS4 VDOT* } [2]	*3.27E+11*					
Future Load [4]	*1.61E+10*					
Powhite Creek	**3.34E+12**	**3.31E+14**		**3.34E+14**	**1.21E+15**	**72.3%**
VAG404219 [1]	*1.74E+09*					
Future Load [4]	*3.34E+12*					
Reedy Creek	**6.117E+13**	**1.183E+14**		**1.795E+14**	**1.797E+14**	**0.1%**
MS4 City of Richmond *MS4 VDOT* } [2]	*5.836E+13*					
MS4 Chesterfield County *MS4 VDOT* } [2]	*2.596E+12*					
Future Load [4]	*2.154E+11*					
James River (lower) impaired (VAP-H39R-08)	**3.06E+15**	**3.40E+15**	***Implicit***	**6.46E+15**	**2.54E+17**	**97.5%**
VA0024163 [1]	*3.48E+10*					
VA0027910 [1]	*1.74E+11*					
VA0063649 [1]	*6.97E+09*					
VA0090727 [1]	*4.36E+11*					
MS4 City of Richmond *MS4 VDOT* } [2]	*1.79E+13*					
MS4 Chesterfield County *MS4 VDOT* } [2]	*1.98E+13*					
MS4 Henrico County *MS4 VDOT* } [2]	*3.50E+13*					
VA0063177: CSOs [3]	*2.99E+15*					
Future Load [4]	*2.39E+12*					

Table ES.1 Average annual in-stream cumulative *E. coli* loads (cfu/year) modeled after allocation in the James River – City of Richmond impairments (continued).

Impairment	WLA[1]	LA	MOS	TMDL	Existing Load	Percent Reduction
James River (tidal) (VAP-G01E-01)	**6.98E+14**	**1.84E+14**	*Implicit*	**8.82E+14**	**1.38E+15**	**36.2%**
VA0002780 [1, 5]	*5.23E+12*					
VA0003077 [1]	*1.74E+12*					
VA0024163 [1]	*2.61E+10*					
VA0024996 [1]	*1.76E+13*					
VA0027910 [1]	*1.22E+11*					
VA0028622 [1]	*1.57E+11*					
VA0060194 [1]	*4.70E+13*					
VA0063177 [1]	*4.44E+14*					
VA0063649 [1]	*6.27E+09*					
VA0063690 [1]	*1.31E+14*					
VA0066494 [1]	*2.61E+10*					
VA0090727 [1]	*4.36E+11*					
VA0085499 [1]	*7.00E+12*					
VAG404078 [1]	*1.74E+09*					
VAG404208 [1]	*1.74E+09*					
VAG404145 [1]	*1.74E+09*					
VAG404175 [1]	*1.74E+09*					
VAG404201 [1]	*1.74E+09*					
VAG404224 [1]	*1.74E+09*					
VAG404223 [1]	*1.74E+09*					
VAG404029 [1]	*1.74E+09*					
VAG404247 [1]	*1.74E+09*					
VAG404224 [1]	*1.74E+09*					
VAG404033 [1]	*1.74E+09*					
VAG404248 [1]	*1.74E+09*					
MS4 Defense Supply Center [2]	*4.49E+10*					
MS4 John Tyler Com. Coll. [2]	*5.03E+09*					
MS4 City of Richmond *MS4 VDOT* } [2]	*9.43E+11*					
MS4 Chesterfield County *MS4 VDOT* } [2]	*2.65E+12*					
MS4 Henrico County *MS4 VDOT* } [2]	*1.36E+12*					
VA0063177: CSOs [3]	*3.04E+13*					
Future Growth [4]	*8.82E+12*					

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] The WLA associated with the combined sewer system will be addressed through the performance standards for the facilities in the approved Long Term Control Plan (LTCP). If WQSs are not attained after the completion of CSO LTCP as determined by post-construction monitoring, additional steps may be required per EPA CSO Policy at IV.B.2.g.
[4] The WLA reflects an allocation for potential future permits issued for bacteria control.
[5] Facility currently operating at Tier 1 – industrial discharge, which is not believed to contribute bacteria. Upon the issuance of a CTO for Tiers 2 & 3, the municipal discharge WLA of 3.0 MGD will apply.

Table ES.2 Final allocations scenarios for the James River - City of Richmond impairments to meet the 126 cfu/100mL E. coli geometric mean standard.

	Percent Reductions to Sources of *E. coli* bacteria						
Stream	**Wildlife Direct**	**Barren, Commercial, Forest, HIR, Wetlands**	**Livestock Direct**	**Cropland, Pasture, LAX**	**Straight Pipes and overflows**	**Human and Pet Land Based (IR)**	**City of Richmond's Long Term Control Plan**
Almond Creek	0	0	91	0	100	85	Alternative E and a 52% reduction
Bernards Creek	0	38	99	93	100	96	NA
Falling Creek	0	0	0	0	100	13	NA
Gillie Creek	0	0	0	0	100	94	Alternative E and a 95% reduction
Goode Creek	0	0	0	0	100	96	NA
No Name Creek	0	0	0	0	100	94.5	NA
Powhite Creek	0	0	40	0	100	86	NA
Reedy Creek	0	0	0	0	100	0	NA
James River (lower)	0	63	96	99	100	99	Alternative E
James River (tidal)	0	0	0	0	100	0	Alternative E

Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standard. The first step in this process is to develop TMDLs that will result in meeting water quality standard. This report represents the culmination of that effort for the impairments in the James River – City of Richmond watershed. The second step is to develop a TMDL implementation plan (IP). The final step is to implement the TMDL IP and to monitor stream water quality to determine if water quality standards are being attained.

While section 303(d) of the Clean Water Act (CWA) and current United States Environmental Protection Agency (EPA) regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Once a TMDL IP is developed, VADEQ will take the plan to the State Water Control Board (SWCB) for approval for implementing the pollutant allocations and reductions contained in the TMDL. Also, VADEQ will request SWCB authorization to incorporate the TMDL implementation plan into the appropriate waterbody. With successful completion of implementation plans, Virginia begins the process of restoring impaired waters and enhancing the value of this important resource.

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, to address the bacteria TMDL, reducing the human bacteria loading from straight pipes and failing septic systems should be a primary implementation focus because of the health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system installation/repair program. Livestock exclusion from streams has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the direct cattle deposits and by providing additional riparian buffers. Reduced trampling and soil shear on streambanks by livestock has been shown to reduce bank erosion.

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned, a new designated use, or a subcategory of a use, the current designated use must be removed. The state must also demonstrate that attaining the designated use is not feasible. Information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens as well as EPA will be able to provide comment during this process.

Public Participation

During development of the TMDL for the impairments in the James River – City of Richmond study area, public involvement was encouraged through a kickoff meeting

(4/4/2006, 15 attendees), a TAC meeting (7/25/2006, 20 attendees), a first public meeting (7/25/2006, 34 attendees), two final public meetings (3/10/2009, 30 attendees in the afternoon; 17 attendees in the evening), and a supplemental public meeting to discuss changes resulting from public comments (6/30/2010). An introduction of the agencies involved, an overview of the TMDL process, details of the pollutant sources, and the specific approach to developing the James River – City of Richmond TMDLs were presented at the first of the public meeting. Public understanding of and involvement in, the TMDL process was encouraged. Input from this meeting was utilized in the development of the TMDL and improved confidence in the allocation scenarios. The final model simulations and the TMDL load allocations were presented during the final public meeting. There was a 30-day public comment period after the final public meeting. Nine groups sent written comments, which were addressed in the final document. A supplemental meeting was held to discuss the changes in the document that resulted from comments received. This meeting was followed by an additional 30-day comment period.

1. INTRODUCTION

1.1 Background

The Clean Water Act (CWA) that became law in 1972 requires that all U.S. streams, rivers, and lakes meet certain water quality standards. The CWA also requires that states conduct monitoring to identify waters that are polluted or do not otherwise meet standards. Through this required program, the state of Virginia has found that many stream segments do not meet state water quality standards for protection of the six beneficial uses: recreation/swimming, aquatic life, wildlife, fish consumption, shellfish consumption, and public water supply (drinking).

When streams fail to meet standards, Section 303(d) of the CWA and the U.S. Environmental Protection Agency's (EPA) Water Quality Management and Planning Regulation (40 Code of Federal Regulation (CFR) Part 130) both require that states develop a Total Maximum Daily Load (TMDL) for each pollutant. A TMDL is a "pollution budget" for a stream; that is, it sets limits on the amount of pollution that a stream can tolerate and still maintain water quality standards. In order to develop a TMDL, background concentrations, point source loadings, and nonpoint source loadings are considered. A TMDL accounts for seasonal variations and must include a margin of safety (MOS).

Once a TMDL is developed and approved by EPA, measures must be taken to reduce pollution levels in the stream. Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) states in section 62.1-44.19:7 that the *"Board shall develop and implement a plan to achieve fully supporting status for impaired waters"*. The TMDL Implementation Plan (IP) describes control measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), which should be implemented in a staged process. Through the TMDL process, states establish water-quality based controls to reduce pollution and meet water quality standards.

The study area for this project is the part of the James River that flows through the City of Richmond and the impaired tributaries within this watershed (Figure 1.1). This area is contained within USGS Hydrologic Unit Codes 02080205 and 02080206. The study area includes portions of Virginia's Chesterfield, Powhatan, Goochland, and Henrico counties. The Virginia Department of Environmental Quality (VADEQ) has identified all of these segments as impaired with regard to fecal bacteria. For the purposes of this report, this watershed shall be referred to as the James River – City of Richmond.

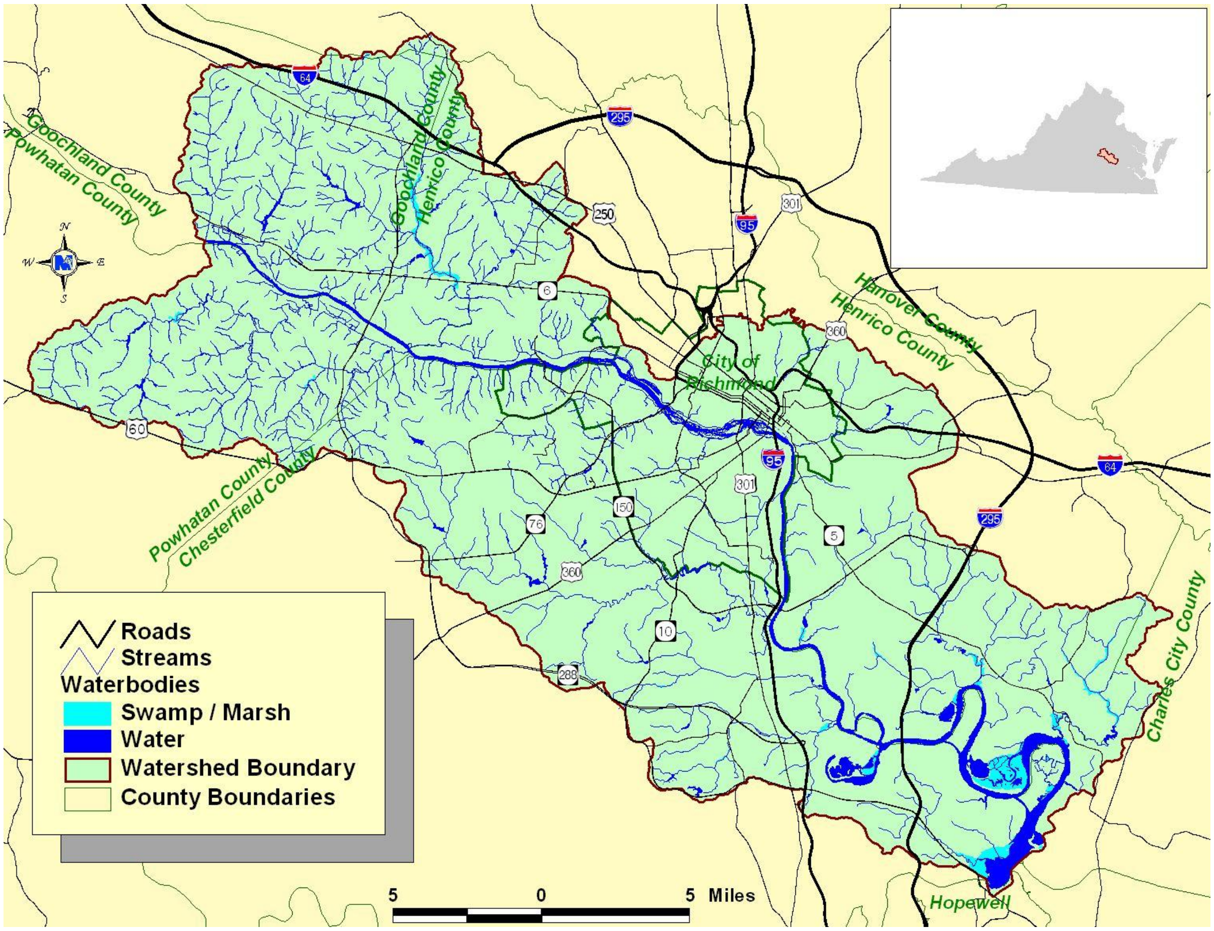

Figure 1.1 Location of the James River – City of Richmond study area watershed.

Table 1.1 lists, for each impairment, the type of impairment, the VADEQ water quality monitoring station used for impaired waters assessment, the initial year that the segment was listed in the Section 303(d) list, current miles affected in the 2004 listing, fecal coliform violation rates in the 2002 and the 2004 lists, and the location of listing. Figure 1.2 shows the current impaired segments.

The James River (H39R-08) and the tidally influenced section of the James River (G01E-01) were initially listed in 1996 for violations of the fecal coliform (FC) standard. Almond Creek was first listed on the *1998 303(d) Total Maximum Daily Load Priority List and Report* for fecal coliform standard violations. The Falling Creek, Goode Creek, Powhite Creek and Reedy Creek segments were placed on the *Virginia 2002 Section 303(d) Report on Impaired Waters* for violations of the fecal coliform standards. Bernards Creek, Gillie Creek, James River H39R-11, and No Name Creek were added to the *Virginia 2004 Section 305(b)/303(d) Water Quality Assessment Integrated Report*. Elevated levels of fecal coliform bacteria recorded at VADEQ ambient water quality monitoring stations showed that these James River stream segments do not support the primary contact recreation use.

While this study area combines rural, residential, and urban land uses, another source of fecal bacteria in this area originates from the urban infrastructure. As in many older cities in the U.S., areas of Richmond have a combined sewer system. A combined sewer system is designed to carry both sewage and storm water to the treatment plant simultaneously. This means that although much of the urban storm water is treated at the sewage treatment plant, when a large rainfall or snowmelt occurs, water flow in this network of pipes increases dramatically, and can exceed the maximum capacity of the sewer systems. Therefore, to avoid toilets and sinks overflowing with raw sewage, the sewer systems are designed to overflow the excess water directly into bodies of water without treatment. This type of event is referred to as a Combined Sewer Overflow (CSO) and can discharge high concentrations of fecal bacteria to the receiving stream(s). The Almond Creek (G01R-02), Gillie Creek (G01R-06), and James River (H39R-08, G01E-01) impairments are each impacted by CSOs.

Originally, for the purposes of this TMDL, the James River main stem was divided into three impaired segments with an upstream reach that was not impaired (See Table 1.1). During the development of this project, subsequent updates to the 303(d)/305(b) impaired waters lists have been completed. The updates include James River segments, which have been removed from the list.

A James River upper segment (known as VAP-H39R-11) was delisted in 2006 by meeting the primary contact recreational use. Later, a portion of the James River lower segment (VAP-H39R-08) was delisted in 2008 by meeting the primary contact recreational use. This lower delisted segment flows from the Williams' Island Dam to the Boulevard Bridge. The updated current impaired segment description is from the Boulevard Bridge to the fall line.

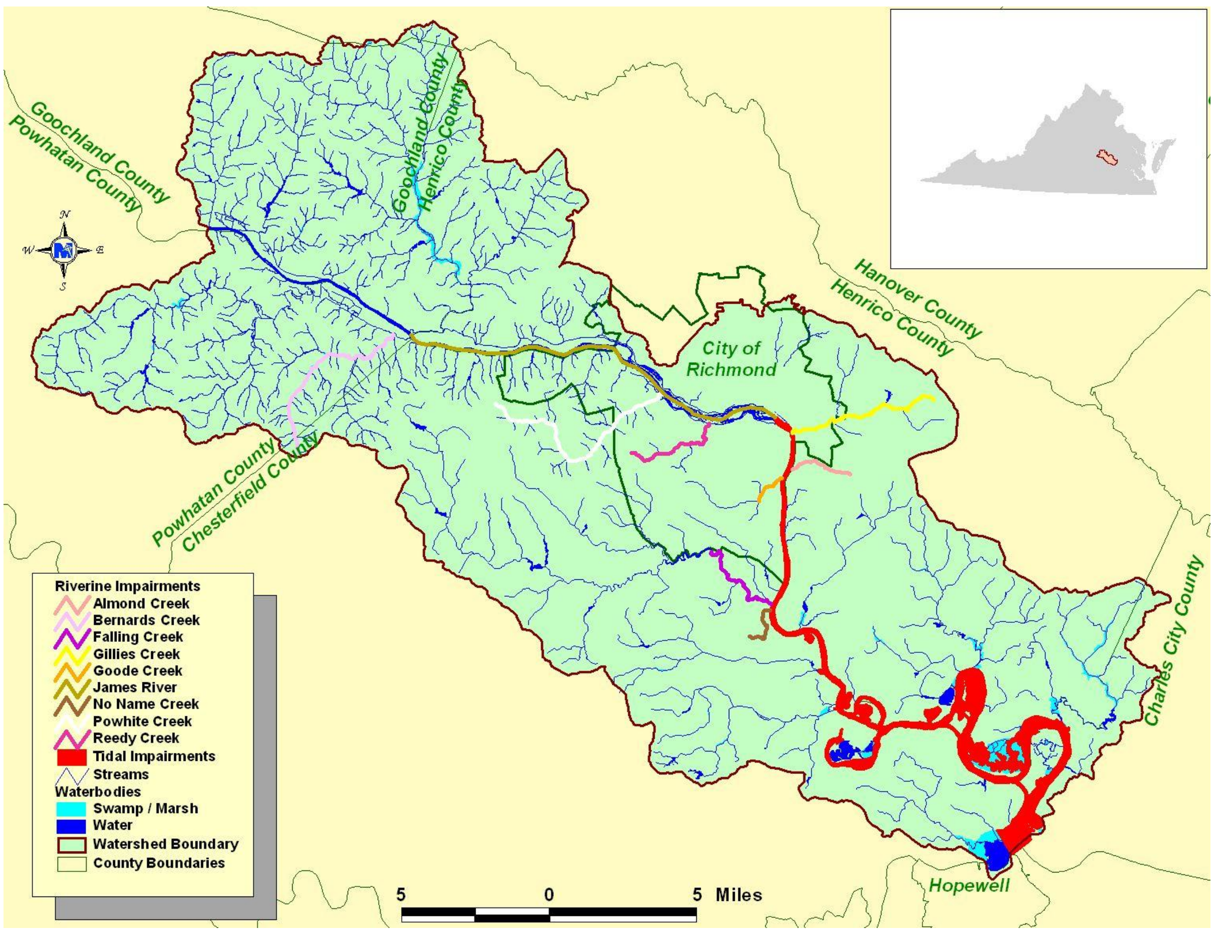

Figure 1.2 2004 Impaired stream segments in the James River – City of Richmond study area.

Table 1.1 Fecal coliform impairments on the *2004 Section 305(b)/303(d) Water Quality Integrated Report* within the James River – City of Richmond study area.

Stream Name HUP	Listing Station ID(s)	Initial Listing Year	River Length Affected (miles)	2002 303(d) List FC Violations/ Total Samples	2004 303(d) List FC Violations/ Total Samples	Location
Almond Creek VAP-G01R-02	2-ALM000.42	1998	2.26	5/27	12/29	From its headwaters to its mouth at the James River, including unnamed tributaries
Bernards Creek VAP-H39R-10	2-BOR0001.73	2004	6.97	NA	7/30	Mainstem of Bernards Creek
Falling Creek VAP-G01R-03	2-FAC000.85	2002	3.81	8/47	10/49	From the Falling Creek Reservoir Dam to confluence with James River
Gillie Creek VAP-G01R-06	2-GIL000.42	2004	5.79	NA	2/9	From its headwaters to its mouth at the James River
Goode Creek VAP-G01R-01	2-GOD000.77	2002	1.23	12/21	14/20	From the confluence with Broad Rock Creek to its mouth at the James River
James River (upper) H39R-11 **DELISTED**	2-JMS117.35	2004	10.06	NA	6/46	The mainstem of the James River between the confluence of Tuckahoe Creek and William's Island Dam
James River (lower) VAP-H39R-08 **DELISTED**	2-JMS115.29	1996	3.05	9/30	--	William's Island Dam at river mile 116.30 to Boulevard Bridge
James River (lower) VAP-H39R-08	2-JMS112.79	1996	2.99	9/30	--	Boulevard Bridge to the fall line at Mayos Bridge
James River (tidal) VAP-G01E-01	2-JMS110.31	1996	10.84 sq. mi.	--	--	From the fall line at Mayos Bridge downstream to the Appomattox River
No Name Creek VAP-G01R-08	2-XTC000.08 2-XUH000.01 2-XUI0000.01	2004	1.83	NA	2/2 1/1 2/2	Unnamed Trib to James River (a.k.a. No Name Creek) mainstem and tribs
Powhite Creek VAP-H39R-05	2-PWT000.57	2002	8.12	3/19	6/28	From its headwaters to its mouth at the James River
Reedy Creek VAP-H39R-06	2-RDD000.19	1998	3.68	8/26	7/18	From its headwaters to its mouth at the James River

2. TMDL ENDPOINT AND WATER QUALITYASSESSMENT

2.1 Applicable Water Quality Standards

According to 9 VAC 25-260-5 of Virginia's State Water Control Board *Water Quality Standards*, the term "water quality standards" means "…provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law and the federal Clean Water Act."

As stated in Virginia state law 9 VAC 25-260-10 (Designation of uses),

> *A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*
>
> ♦
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

Virginia adopted its current *E. coli* and *enterococci* standards in January 2003 and they were updated in 2009. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals; there is a strong correlation between these and the incidence of gastrointestinal illness. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination.

The criteria which were used in developing the bacteria TMDL in this study are outlined in Section 9 VAC 25-260-170 (Bacteria; other recreational waters) and read as follows:

> *A. The following bacteria criteria (colony forming units (cfu)/100mL) shall apply to protect primary contact recreational uses in surface waters, except waters identified in subsection B of this section:*

E. coli bacteria shall not exceed a monthly geometric mean of 126 cfu/100mL in freshwater. Enterococci bacteria shall not exceed a monthly geometric mean of 35 cfu/100mL in transition and saltwater.

1. *See 9VAC25-260-140 C for boundary delineations for freshwater, transition and saltwater.*
2. *Geometric means shall be calculated using all data collected during any calendar month with a minimum of four weekly samples.*
3. *If there [are] insufficient data to calculate monthly geometric means in freshwater, no more than 10% of the total samples in the assessment period shall exceed 235 E. coli cfu/100mL.*
4. *If there [are] insufficient data to calculate monthly geometric means in transition and saltwater, no more than 10% of the total samples in the assessment period shall exceed enterococci 104 cfu/100mL.*
5. *For beach advisories or closures, a single sample maximum of 235 E. coli cfu/100mL in freshwater and a single sample maximum of 104 enterococci cfu/100mL in saltwater and transition zones shall apply.*

B. The following bacteria criteria per 100mL (cfu/100mL) of water shall apply to protect secondary contact recreational uses in surface waters:

E. coli bacteria shall not exceed a monthly geometric mean of 630 cfu/100mL in freshwater. Enterococci bacteria shall not exceed a monthly geometric mean of 175 cfu/100mL in transition and saltwater.

1. *See 9VAC25-260-140 C for boundary delineations for freshwater, transition and saltwater.*
2. *Geometric means shall be calculated using all data collected during any calendar month with a minimum of four weekly samples.*
3. *If there [are] insufficient data to calculate monthly geometric means in freshwater, no more than 10% of the total samples in the assessment period shall exceed 1173 E. coli cfu/100mL.*
4. *If there [are] insufficient data to calculate monthly geometric means in transition and saltwater, no more than 10% of the total samples in the assessment period shall exceed enterococci 519 cfu/100mL.*
5. *Where the existing water quality for bacteria is below the geometric mean criteria in a water body designated for secondary contact in subdivision 6 of this subsection that higher water quality will be maintained in accordance with 9VAC25-260-30 A 2.*

2.2 Selection of a TMDL Endpoint

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the bacteria impairments in the James River – City of Richmond study area, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations. In order to remove a waterbody from a state's list of impaired waters, the Clean Water Act requires compliance with that state's water quality standard.

Since modeling provided simulated output of *E. coli* concentrations at 1-hour intervals, the assessment of TMDLs was made using the geometric mean standard of 126 cfu/100 ml. Therefore, the in-stream *E. coli* target for this TMDL was a monthly geometric mean not exceeding 126 cfu/100 ml. The tidal fresh impaired segment of the James River (VAP-G01E-01) is not an estuary, as it does not receive salt water, however for modeling purposes this segment is hydrologically affected by the tides. Therefore, it must meet the *E. coli* standard above, rather than the Enterococci standard.

2.3 Discussion of In-stream Water Quality

This section provides an inventory and analysis of available observed in-stream fecal coliform monitoring data in the watershed of the James River – City of Richmond study area. An examination of data from water quality stations used in the 303(d) assessment was performed and data collected during TMDL development were analyzed. Sources of data and pertinent results are discussed.

2.3.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information are:

- Bacteria enumerations from 85 VADEQ in-stream monitoring stations,
- Bacteria enumerations from 17 sites in the James River, monitored for permit compliance purposes,

- Bacteria enumerations from 7 citizen monitoring sites in Reedy Creek and one in Crooked Branch, and
- Bacterial source tracking at 15 VADEQ stations.

2.3.1.1 VADEQ Water Quality Monitoring for TMDL Assessment

Data from in-stream water samples, collected at VADEQ monitoring stations from January 1990 through January 2006 (Figure 2.1), were analyzed for fecal coliform (Table 2.1). Samples were taken for the purpose of determining compliance with the state instantaneous standard limiting concentrations to 400 cfu/100 mL or less. As a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 mL or in excess of a specified cap (*e.g.*, 8,000 or 16,000 cfu/100 mL, depending on the laboratory procedures employed for the sample) were not analyzed further to determine the precise concentration of fecal coliform bacteria. The result is that reported values of 100 cfu/100 mL most likely represent concentrations below 100 cfu/100 mL, and reported concentrations of 8,000 or 16,000 cfu/100 mL most likely represent concentrations in excess of these values. *E. coli* samples were also collected to evaluate compliance with the state's current bacterial standard. Tables 2.2 and 2.3 summarize the fecal coliform and enterococci samples collected at the in-stream monitoring stations. The tables are arranged in alphabetical order by stream name then from upstream to downstream station location. Additionally, Appendix A presents the data graphically in a frequency analysis of fecal coliform concentrations.

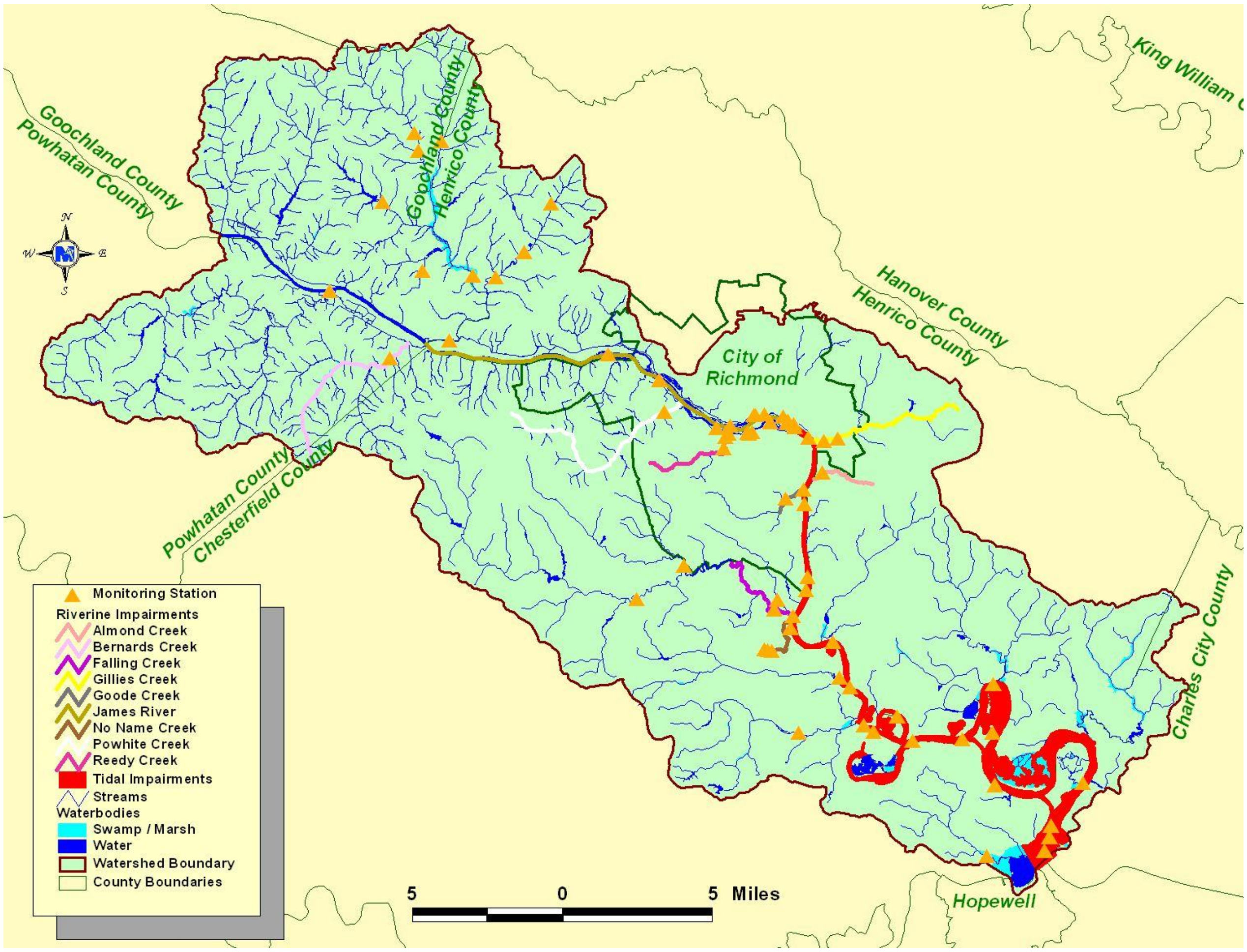

Figure 2.1 Location of VADEQ water quality monitoring stations in the James River – City of Richmond study area.

Table 2.1 Summary of fecal coliform (cfu/100 mL) data collected by VADEQ from April 1970 - August 2007.

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation %
Almond Creek	2-ALM000.42	5/72 – 5/03	265	20	16,000	2,009	500	2,502	52
Bernards Creek	2-BOR001.73	8/97 - 5/03	36	18	7,100	647	100	1,628	19
Broad Branch	2-BOD002.19	8/01 - 5/03	11	100	3,100	809	200	1,013	36
Cornelius Creek	2-CEL001.00	11/20/2001	1	100	100	NA	NA	NA	0
Deep Run	2-DPR004.38	6/03 - 3/04	10	50	2,000	983	725	915	60
Deep Run	2-DPR002.46	7/97 - 3/04	60	25	16,000	1,925	545	3,601	53
Deep Run	2-DPR001.00	6/01 - 5/03	14	100	8,000	1,007	100	2,236	29
Falling Creek	2-FAC009.46	5/01 - 11/05	28	25	2,000	359	100	564	18
Falling Creek	2-FAC000.85	1/80 - 3/06	215	18	16,000	533	100	1,027	18
Gillie Creek	2-GIL000.03	9/72 – 7/74	16	100	60,000	8,525	6,000	14,153	94
Gillie Creek	2-GIL001.00	6/01 - 5/03	12	100	8,000	1,583	600	2,546	50
Gillie Creek	2-GIL000.42	1/80 - 2/89	82	100	8,000	1,924	400	2,818	48
Goode Creek	2-GOD000.77	8/97 - 4/01	23	18	16,000	3,489	1,100	5,207	70
Grindall Creek	2-GRK000.57	1/80 - 6/90	107	100	8,000	1,474	600	2,217	54
James River	2-JMS127.50	6/01 - 7/06	14	50	4,200	632	100	1,210	29
James River	2-JMS117.35	1/80 - 12/06	270	18	16,000	355	100	1,140	14
James River	2-JMS115.29	7/94 - 9/04	105	18	16,000	773	93	2,672	15
James River	2-JMS112.79	9/95 - 9/04	87	18	16,000	1,328	170	3,505	29
James River	2-JMS112.37	9/95 - 8/01	70	18	16,000	3,630	700	5,799	61
James River	2-JMS112.33	9/95 - 8/04	84	18	16,000	1,687	170	3,969	35
James River	2-JMS111.55	6/94 - 8/01	88	18	16,000	3,494	745	5,474	58
James River	2-JMS111.48	6/94 - 8/01	88	18	16,000	6,792	2400	7,199	74
James River	2-JMS111.47	7/94 - 8/04	101	18	16,000	1,696	220	3,950	34
James River	2-JMS111.35	6/94 - 8/01	87	18	16,000	1,901	240	4,233	40
James River	2-JMS111.32	6/94 - 8/01	94	20	16,000	6,003	1300	6,911	71
James River	2-JMS111.17	9/95 - 8/04	102	20	16,000	2,574	330	5,008	44
James River	2-JMS110.90	6/94 - 8/01	86	18	16,000	1,794	235	3,972	41

Table 2.1 Summary of fecal coliform (cfu/100 mL) data collected by VADEQ from April 1970 - August 2007 (cont.).

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation %
James River	2-JMS110.49	9/95 - 8/01	70	20	16,000	3,787	595	6,049	57
James River	2-JMS110.31	6/94 - 8/01	87	18	16,000	3,460	460	5,716	49
James River	2-JMS110.30	1/80 - 8/07	432	3	16,000	666	100	2,110	19
James River	2-JMS110.07	6/94 - 8/01	88	18	16,000	5,323	1,300	6,614	75
James River	2-JMS109.98	7/83 - 9/83	3	237	540	429	512	168	67
James River	2-JMS109.39	5/80 - 8/01	95	18	16,000	2,330	330	4,608	43
James River	2-JMS107.51	6/94 - 8/01	85	18	16,000	3,111	490	5,514	55
James River	2-JMS107.04	5/80 - 9/83	14	48	8,000	1,492	250	2,622	36
James River	2-JMS104.58	6/94 - 8/01	85	18	16,000	2,415	330	4,885	45
James River	2-JMS104.16	5/80 - 1/06	158	18	16,000	696	100	2,438	24
James River	2-JMS103.15	9/83 - 8/01	86	18	16,000	2,061	320	4,418	42
James River	2-JMS102.76	5/80 - 9/83	14	100	5,575	885	200	1,554	29
James River	2-JMS101.03	7/94 - 8/01	84	18	16,000	1,738	170	4,000	36
James River	2-JMS099.30	5/80 - 1/06	282	11	47,325	1,305	100	6,310	24
James River	2-JMS097.77	4/70 – 9/83	74	9	80,000	2,361	200	9,527	35
James River	2-JMS097.41	7/94 – 8/01	84	0	16,000	873	110	2,670	25
James River	2-JMS096.22	7/94 – 8/01	84	0	16,000	902	78	3,012	20
James River	2-JMS094.96	4/70 – 8/01	120	0	54,000	1,607	110	5,818	28
James River	2-JMS093.21	7/94 – 8/01	84	0	16,000	953	45	3,405	18
James River	2-JMS091.00	7/94 – 8/01	83	0	16,000	747	45	2,996	12
James River	2-JMS088.81	7/94 – 8/01	84	0	9,200	242	20	1,124	4
James River	2-JMS087.01	5/74 – 1/06	264	0	16,000	559	100	2,108	16
James River	2-JMS080.76	7/94 – 8/01	81	18	16,000	691	45	2,685	15
James River	2-JMS078.99	4/70 – 8/01	118	0	16,000	944	100	2,828	23
James River	2-JMS078.62	5/75 – 6/83	33	100	2,900	282	100	620	9
James River	2-JMS078.07	7/83 – 9/83	6	43	230	122	93	87	0

Table 2.1 Summary of fecal coliform (cfu/100 mL) data collected by VADEQ from April 1970 - August 2007 (cont.).

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation %
Johnson Creek	2-JOD001.96	9/74 – 6/79	39	100	6,000	454	100	1,024	21
Johnson Creek	2-JOD001.19	5/01 – 6/03	14	100	700	186	100	161	7
Jones Creek	2-JOH004.23	4/05	1	120	120	NA	NA	NA	0
Kingsland Creek	2-KSL000.18	1/80 - 6/90	107	100	8,000	769	200	1,304	39
Little Tuckahoe Creek	2-LIY001.73	7/97 - 3/04	54	20	16,000	1,398	330	3,082	43
No Name Creek	2-XSZ002.24	10/02	1	100	100	NA	NA	NA	0
Norwood Creek	2-NWD004.15	4/03	1	75	75	NA	NA	NA	0
Pocoshock Creek	2-PSK000.23	7/01 - 6/03	12	100	7,700	858	150	2,177	17
Powhite Creek	2-PWT001.97	1/00	1	25	25	NA	NA	NA	0
Powhite Creek	2-PWT000.57	1/80 - 5/03	154	18	16,000	719	200	1,251	26
Proctors Creek	2-PCT002.46	1/80 - 6/90	105	100	8,000	655	200	1,253	30
Reedy Creek	2-RDD000.76	2/80 - 6/90	107	46	16,000	2,636	1300	3,889	76
Reedy Creek	2-RDD000.19	7/94 - 1/01	32	18	16,000	1,703	240	3,521	41
Tuckahoe Creek	2-TKO010.64	7/97 - 4/01	43	18	16,000	826	230	2,524	30
Tuckahoe Creek	2-TKO010.24	6/03 - 3/04	10	25	880	334	210	275	30
Tuckahoe Creek	2-TKO004.69	1/90 - 3/04	91	18	16,000	805	130	2,565	20
Tuckahoe Creek	2-TKO000.81	6/03 - 3/04	9	25	880	312	250	302	22
Unnamed Trib to XCZ	2-XHP000.42	4/02 - 3/04	12	20	2,000	491	175	728	33
X-Trib to No Name Creek	2-XVL000.04	10/02	1	100	100	NA	NA	NA	0
X-Trib to No Name Creek	2-XUI000.01	3/02 - 10/02	2	600	2,600	1,600	1600	1,414	50
X-Trib to No Name Creek	2-XUH000.01	10/02	1	1,700	1,700	NA	NA	NA	0
X-Trib to No Name Creek	2-XTC000.08	3/02 - 10/02	2	600	2,100	1,350	1350	1,061	50

Table 2.2 Summary of *E. coli* (cfu/100 mL) data collected by VADEQ from January 2000 - April 2008.

Stream	Station	Dates	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation %
Almond Creek	2-ALM000.42	2/00 – 1/06	9	1	800	199	80	280	33
Bernards Creek	2-BOR001.73	1/06 - 3/08	19	10	1,300	131	60	288	5
Bernards Creek	2-BOR003.61	1/06 - 12/06	12	4	580	127	25	200	17
Deep Run	2-DPR004.38	6/03 - 3/04	10	10	800	263	100	311	40
Deep Run	2-DPR002.46	3/00 - 3/04	24	10	800	277	200	258	33
Dover Creek	2-DOV000.42	7/03 - 3/05	10	25	350	65	25	102	10
Genito Creek	2-GEN000.69	6/05 - 12/06	10	50	450	160	88	150	20
Gillie Creek	2-GIL002.84	1/06 – 3/06	3	1	1	1	1	0	0
James River	2-JMS087.01	7/04 – 1/06	18	25	500	97	25	130	11
James River	2-JMS110.30	7/04 - 4/08	45	25	650	142	100	164	16
James River	2-JMS111.17	5/00 - 11/07	68	3	5,600	197	77	688	12
James River	2-JMS111.47	5/00 - 11/07	67	1	1,440	112	60	212	8
James River	2-JMS112.33	5/00 - 11/07	63	2	8,000	237	46	1,018	11
James River	2-JMS112.79	5/00 - 11/07	68	1	1,195	116	59	193	12
James River	2-JMS115.29	6/03 - 4/08	57	1	1,345	79	36	182	4
James River	2-JMS117.35	7/03 - 4/08	47	1	2,000	98	25	297	4
James River	2-JMS127.50	7/06	1	25	25	NA	NA	NA	0
Jones Creek	2-JOH004.23	4/07	1	60	60	NA	NA	NA	0
Little Tuckahoe Creek	2-LIY001.73	3/00 - 12/06	33	10	1,300	320	250	312	52
Norwood Creek	2-NWD005.84	6/05 - 12/06	10	25	300	58	25	87	10
Norwood Creek	2-NWD004.15	4/07	1	30	30	NA	NA	NA	0
Norwood Creek	2-NWD002.27	7/03 - 3/05	9	12	700	121	25	221	11
Powhite Creek	2-PWT000.57	1/06 - 12/06	13	4	3,300	293	15	907	15
Powhite Creek	2-PWT001.97	1/00	1	10	10	NA	NA	NA	0

Table 2.2 Summary of *E. coli* (cfu/100 mL) data collected by VADEQ from January 2000 - April 2008 (cont.).

Stream	Station	Dates	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation %
Powhite Creek	2-PWT003.98	1/06 - 1/07	13	4	1,400	141	37	379	8
Powhite Creek	2-PWT006.02	1/06 - 1/07	13	1	570	124	54	162	15
Powhite Creek	2-PWT007.20	1/06 - 12/06	12	14	330	113	66	114	17
Reedy Creek	2-RDD000.19	1/06 - 12/06	22	9	7,700	543	51	1,651	27
Tuckahoe Creek	2-TKO000.81	6/03 - 3/04	9	10	250	101	120	91	11
Tuckahoe Creek	2-TKO004.69	6/03 - 3/08	28	7	1,600	151	60	320	7
Tuckahoe Creek	2-TKO010.24	6/03 - 3/05	20	10	2,000	270	120	472	15
Unnamed Trib to James River	2-XXC000.19	6/05 - 12/05	4	25	75	38	25	25	0
Unnamed Trib to XCZ	2-XHP000.42	6/03 - 3/04	10	10	800	174	100	237	20

Table 2.3 Summary of *enterococci* (cfu/100 mL) data collected by VADEQ from May 2000 through March 2007.

Stream	Station	Dates	Count	Minimum	Maximum	Mean	Median	Standard Deviation
James River	2-JMS111.17	5/00 - 8/04	33	10	800	173	110	198
James River	2-JMS111.47	5/00 - 8/04	33	10	900	191	140	246
James River	2-JMS112.33	5/00 - 8/04	31	10	900	253	130	268
James River	2-JMS112.79	5/00 - 9/04	34	30	1,600	325	220	324
James River	2-JMS115.29	6/03 - 9/04	16	10	600	124	60	147
James River	2-JMS117.35	7/03 - 5/04	6	10	650	182	55	254
Little Tuckahoe Creek	2-LIY001.73	3/00 - 3/04	23	10	800	377	360	287
Powhite Creek	2-PWT001.97	3/07	1	10	10	NA	NA	NA
Tuckahoe Creek	2-TKO004.69	6/03 - 3/04	10	20	800	281	200	262

2.3.1.2 Permit Compliance Monitoring

In order to comply with the James River Waste Water Treatment Plant permit VA006317 (Section 3.2), monitoring of the James River is required. The following tables are summaries of the monitoring by Greeley and Hansen for the City of Richmond (Table 2.4 and 2.5). Figure 2.2 shows the location of the City of Richmond/Greeley and Hansen water quality monitoring stations in the James River –City of Richmond study area. The station number in the tables corresponds to location shown in Figure 2.2.

Table 2.4 Summary of fecal coliform (mpn/100 mL) data collected for the City of Richmond in the James River from September 1996 through February 1997.

Station #	Station Name	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation %[1]
1	Huguenot Bridge	31	2	2,000	366	70	521	29%
2	Mayo's Bridge North Channel	31	7	2,000	389	80	584	26%
3	Mayo's Bridge South Channel	31	8	3,000	453	130	717	26%
5	Above WWTP at Lone Star Cement Co	27	7	5,000	644	130	1,087	37%
6	Buoy 168 Main Channel	27	6	3,000	693	240	837	33%
7	Buoy 166 Main Channel	27	11	2,000	390	80	622	19%
8	Buoy 157 Main Channel	27	20	2,300	598	130	774	33%
9	Buoy 151 Main Channel	27	6	2,200	561	140	737	33%
10	Buoy 146 Main Channel	27	4	4,000	539	170	926	26%

[1] Based on the number of samples greater than 400 mpn/100mL

Table 2.5 Summary of fecal coliform (mpn/100 mL) data collected by Greeley and Hansen in the James River from February 2000 through September 2000.

Station #	Station Name	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation %[1]
1	Huguenot Bridge	55	2	17000	548	80	2362	11
2	Mayo's Bridge North Channel	47	13	24000	1616	170	4756	23
2	Mayo's Bridge North Channel (from boat)	1	1,700	1,700	1,700	1,700	NA	100%
2	Mayo's Bridge North Channel (from bridge)	1	1,300	1,300	1,300	1,300	NA	100%
3	Mayo's Bridge South Channel	47	13	13000	634	220	1898	32
3	Mayo's Bridge South Channel (from boat)	1	800	800	800	800	NA	100%
3	Mayo's Bridge South Channel (from bridge)	1	800	800	800	800	NA	100%
4	Ash Street (ASH)	35	50	24000	1905	230	4993	31%
4	Ancarrow (ANC)	41	20	13000	938	170	2220	29%
6	Buoy 168 Main Channel	5	3,000	90,000	35,000	24,000	35,791	100%
7	Buoy 166 Main Channel	5	130	8,000	1,946	500	3,393	60%
8	Buoy 157 Main Channel	5	130	3,000	814	300	1,231	40%
9	Buoy 151 Main Channel	5	80	9,000	2,378	300	3,827	40%
10	Buoy 146 Main Channel	5	20	130	54	40	44	0%
4	River Bank South Side of River, North of Boat Ramp	5	500	5,000	2,760	3,000	1,616	100%
4	River Bank North Side of River, Boat Ramp at Water and Ash St.	5	800	3,000	2,280	2,400	901	100%
3	Lee Bridge	2	700	800	750	750	71	100%
3	Manchester Bridge	2	1,700	50,000	25,850	25,850	34,153	100%
3	Haxal Head Gate	2	30,000	50,000	40,000	40,000	14,142	100%

NA = Not applicable due to only 1 sample taken
[1] Based on the number of samples greater than 400 mpn/100mL

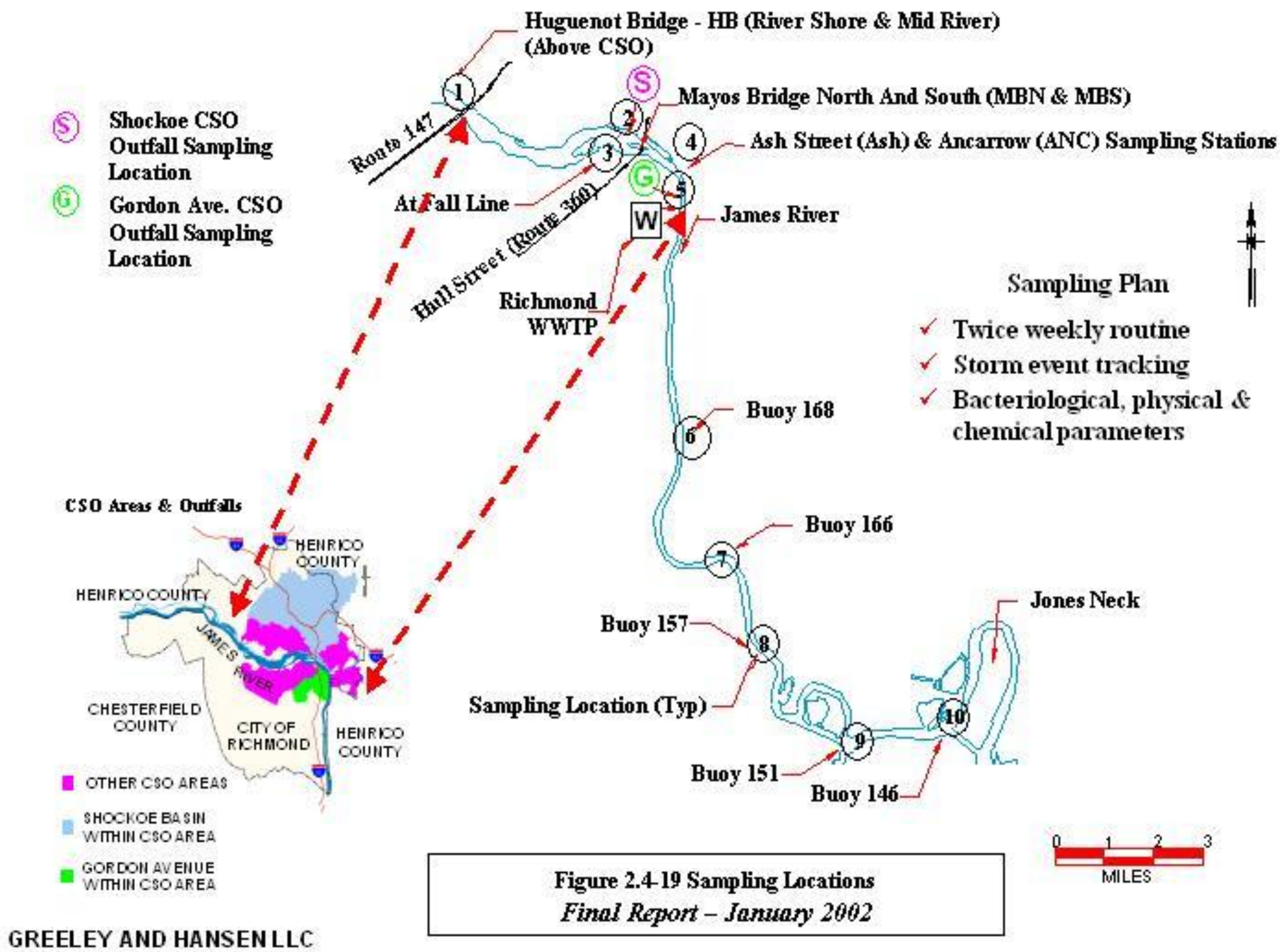

Figure 2.2 Location of City of Richmond/Greeley and Hansen water quality monitoring stations in the James River – City of Richmond study area.

2.3.1.3 Citizen Water Quality Monitoring

Watershed citizens performed water quality monitoring from June 2003 through September 2005. Water quality samples were taken at 7 sites in Reedy Creek and one in Crooked Branch (5), a tributary to Reedy Creek, and were analyzed for *E. coli* (Table 2.6). These stations are organized from upstream to downstream in Table 2.4. Although there is not enough data for a statistical analysis, the *E. coli* concentrations are generally higher at stations 44th Street (4) and Dunston DS-Roanoke (3), before and after the Crooked Branch tributary, respectively. The number in the column heading corresponds to the number in Figure 2.3, which shows the locations of the stations.

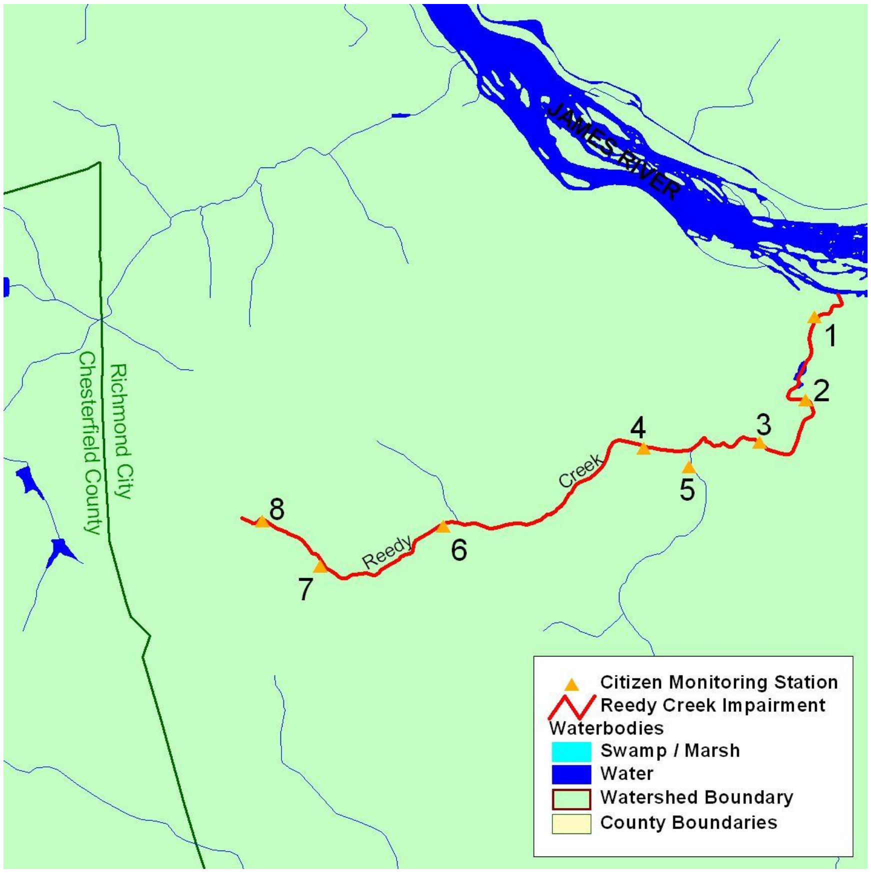

Figure 2.3 Location of citizen water quality monitoring stations in Reedy Creek.

Table 2.6 Citizen monitoring *E. coli* results from Reedy Creek from June 2003 to September 2005.

	***E. coli* (cfu/100 ml) at Station:**							
Date	DS - Deter Road (8)	US - LaBrook Road (7)	DS - Erich Road (6)	44th Street (4)	Crooked Branch (5)	Dunston DS-Roanoke (3)	US - Pond FHP (2)	US - Riverside Drive (1)
6/28/2003	1,350	440	730	> 5,000	190	1,860	430	530
7/19/2003	1,510	1,210	1,230	5,500	450	1,100	780	700
8/16/2003	1,780	1,480	920	2,360	1,120	5,750	2,300	4,000
10/18/2003	400	300	160	530	70	730	280	180
11/15/2003	430	50	40	650	50	160	230	110
12/20/2003	30	10	< 10	< 10	< 10	< 10	150	50
1/24/2004	110	< 10	< 10	NS	< 10	40	50	10
2/21/2004	210	< 10	10	< 10	10	< 10	< 10	< 10
3/20/2004	60	10	10	10	30	50	150	40
4/17/2004	50	100	90	230	10	290	60	60
5/22/2004	6,890	1,810	1,690	6,140	950	3,740	2,500	4,350
6/26/2004	7,760	4,400	6,200	11,960	13,980	13,340	9,540	11,460
7/17/2004	2,180	100	30	> 25,000	NS	1,650	230	80
8/28/2004	1,160	440	> 12,500	3,380	50	650	310	110
9/25/2004	910	60	150	1,930	30	730	180	190
10/23/2004	490	100	110	2,650	40	190	90	50
11/20/2004	140	50	10	150	100	60	40	50
12/18/2004	50	10	< 10	1,030	NS	10	80	30
3/19/2005	190	< 10	10	30	< 10	30	10	< 10
6/4/2005	390	10	400	NS	NS	240	200	100
9/24/2005	> 5,000	NS	NS	> 12,000	NS	990	790	550

US=Upstream; DS=Downstream, NS=No sample taken

2.3.1.4 Bacterial Source Tracking

MapTech, Inc. was contracted to perform an analysis of *E. coli* concentrations as well as bacterial source tracking (BST). BST is intended to aid in identifying sources (*i.e.*, human, pets, livestock, or wildlife) of fecal contamination in water bodies. Data collected provided insight into the likely sources of fecal contamination, aided in distributing fecal loads from different sources during model calibration, and will improve the chances for success in implementing solutions.

Virginia has adopted the Antibiotic Resistance Analysis (ARA) methodology implemented by MapTech's Environmental Detection Laboratory (EDL). This method was selected because it has been demonstrated to be a reliable procedure for confirming the presence of human, pet, livestock and wildlife sources in watersheds in Virginia. The results were reported as the percentage of isolates acquired from the sample that were identified as originating from either humans, pets, livestock, or wildlife.

The BST results of water samples collected at 16 stations in the James River – City of Richmond study area are reported in Tables 2.7 through 2.22. The *E. coli* enumerations are given to indicate the bacteria concentrations at the time of sampling. Bold values in this column represent samples that exceeded the instantaneous (single sample) standard of 235 cfu/100mL.

The proportions (%) reported are formatted to indicate statistical significance (*i.e.*, **Bold** numbers indicate a statistically significant result). The statistical significance was determined through two tests. The first was based on the sample size. A z-test was used to determine if the proportion was significantly different from zero (alpha = 0.10). Second, the rate of false positives was calculated for each source category in each library, and a proportion was not considered significantly different from zero unless it was greater than the false-positive rate plus three standard deviations.

Figure 2.4 shows the location of BST water quality monitoring stations in the James River – City of Richmond area. Table 2.23 summarizes the results for each station with isolate-weighted average proportions of bacteria originating from the four source categories. The isolate-weighted average considers the concentration of *E. coli* measured and the number of bacterial isolates analyzed in the BST analysis. The anthropogenic (human + livestock + pet) bacteria proportion is also shown in this table. This gives an estimation of the overall bacteria load reduction percentage attainable without addressing wildlife loads, which may be useful during implementation plan development.

Table 2.7 Summary of bacterial source tracking results from water samples collected in the Almond Creek impairment (2-ALM000.42).

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
7/19/05	24	122	**17%**	**45%**	**21%**	**17%**
8/23/05	24	199	**92%**	8%	0%	0%
9/20/05	21	36	**48%**	4%	0%	**48%**
10/18/05	24	72	**72%**	12%	8%	8%
11/15/05	16	36	**63%**	6%	**31%**	0%
12/13/05	24	48	**54%**	**21%**	0%	**25%**
1/10/06	3	6	67%	33%	0%	0%
2/8/06	4	4	100%	0%	0%	0%
3/29/06	3	4	33%	0%	0%	67%
4/27/06	7	32	29%	43%	14%	14%
5/16/06	24	**250**	**42%**	**29%**	12%	17%
6/7/06	24	108	**84%**	8%	0%	8%
7/24/06	23	**370**	**91%**	0%	0%	9%
8/29/06	24	**1,440**	**42%**	8%	**21%**	**29%**
9/25/06	24	**1,990**	**84%**	8%	0%	8%
10/31/06	20	74	**95%**	0%	0%	5%
11/28/06	10	12	**60%**	10%	**30%**	0%
12/6/06	7	22	57%	14%	29%	0%
2/14/07	23	**470**	**26%**	**53%**	4%	**17%**
3/19/07	15	18	7%	**20%**	**53%**	**20%**
6/4/07	24	**1,110**	**80%**	8%	12%	0%
6/12/07	24	200	**25%**	**38%**	**25%**	12%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.8 Summary of bacterial source tracking results from water samples collected in the Bernards Creek impairment (2-BOR001.73).

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
1/10/06	24	66	**75%**	**17%**	0%	8%
2/1/06	16	26	**75%**	0%	6%	**19%**
3/1/06	12	24	17%	0%	**50%**	**33%**
4/10/06	24	68	**100%**	0%	0%	0%
5/1/06	20	70	**75%**	0%	5%	**20%**
5/1/06	18	44	**78%**	0%	0%	**22%**
6/5/06	24	66	**96%**	0%	4%	0%
7/11/06	18	90	**61%**	0%	**28%**	11%
8/8/06	1	6	100%	0%	0%	0%
9/5/06	24	**1,600**	**42%**	4%	**42%**	**12%**
10/2/06	24	180	0%	0%	4%	**96%**
11/7/06	14	52	**79%**	7%	14%	0%
12/12/06	24	94	4%	12%	12%	**72%**

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.9 Summary of bacterial source tracking results from water samples collected in the Falling Creek impairment (2-FAC000.85).

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
1/11/06	7	12	14%	43%	0%	43%
2/6/06	24	88	**49%**	**17%**	17%	**17%**
3/13/06	24	48	**80%**	8%	12%	0%
4/11/06	21	34	**71%**	**24%**	0%	5%
5/8/06	24	**630**	**33%**	**17%**	**21%**	**29%**
6/6/06	21	179	**81%**	0%	0%	**19%**
7/17/06	19	94	5%	**37%**	11%	**47%**
8/15/06	18	210	**66%**	6%	11%	**17%**
9/18/06	24	116	**84%**	0%	4%	12%
10/3/06	23	96	**87%**	0%	0%	13%
11/8/06	20	122	**40%**	**30%**	5%	**25%**
12/6/06	21	48	**76%**	10%	0%	14%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.10 Summary of bacterial source tracking results from water samples collected in the Gillie Creek impairment (2-GIL001.00).

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
7/19/05	18	14	**61%**	6%	11%	**22%**
8/23/05	22	**800**	**37%**	**27%**	9%	**27%**
9/20/05	22	46	**36%**	5%	0%	**59%**
10/18/05	13	26	**38%**	8%	**23%**	**31%**
11/15/05	1	2	0%	0%	100%	0%
12/13/05	24	118	**29%**	4%	**38%**	**29%**
1/10/06	24	**879**	**21%**	**42%**	12%	**25%**
2/8/06	22	12	**55%**	**18%**	9%	**18%**
3/29/06	7	16	57%	0%	14%	29%
4/25/06	20	66	**40%**	**20%**	10%	**30%**
5/16/06	24	**330**	**67%**	4%	17%	12%
6/7/06	24	158	**45%**	**17%**	0%	**38%**
7/24/06	23	**1,480**	**49%**	**17%**	17%	**17%**
8/29/06	24	**1,400**	**67%**	0%	12%	**21%**
9/25/06	24	**1,840**	12%	**22%**	**33%**	**33%**
10/31/06	16	120	**94%**	0%	0%	6%
11/28/06	24	**750**	**96%**	0%	4%	0%
12/6/06	16	170	**88%**	0%	6%	6%
2/14/07	23	**2,000**	13%	**22%**	9%	**56%**
3/19/07	24	**770**	12%	**21%**	**63%**	4%
6/4/07	24	**930**	**59%**	**25%**	4%	12%
6/12/07	24	**2,000**	4%	**33%**	**63%**	0%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.11 Summary of bacterial source tracking results from water samples collected in the Goode Creek impairment 2-GOD000.77.

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
7/19/05	24	**243**	**59%**	12%	12%	**17%**
8/23/05	22	161	**50%**	9%	9%	**32%**
9/20/05	24	147	**55%**	**21%**	12%	12%
10/18/05	24	**333**	**33%**	**21%**	4%	**42%**
11/15/05	21	50	5%	**38%**	**57%**	0%
12/13/05	6	12	0%	0%	67%	33%
1/10/06	4	8	100%	0%	0%	0%
3/29/06	3	6	33%	0%	0%	67%
4/27/06	20	80	5%	**40%**	5%	**50%**
5/16/06	24	**730**	**59%**	4%	**25%**	12%
6/7/06	24	**1,220**	**79%**	0%	0%	**21%**
7/24/06	23	**620**	**92%**	0%	4%	4%
8/29/06	24	**1,680**	**59%**	4%	8%	**29%**
9/25/06	24	**2,000**	**75%**	**17%**	0%	8%
10/31/06	15	30	**86%**	0%	7%	7%
11/28/06	12	28	**84%**	8%	8%	0%
12/6/06	8	30	38%	12%	12%	38%
2/14/07	22	170	5%	14%	**32%**	**49%**
3/19/07	20	34	0%	**35%**	**45%**	**20%**
6/4/07	24	**1,470**	**67%**	**17%**	12%	4%
6/12/07	24	**1,040**	**92%**	0%	4%	4%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.12 Summary of bacterial source tracking results from water samples collected in the James River impairment 2-JMS099.30.

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
7/19/05	16	28	**50%**	0%	0%	**50%**
8/23/05	5	16	100%	0%	0%	0%
9/20/05	3	2	100%	0%	0%	0%
10/18/05	15	34	**66%**	0%	**27%**	7%
11/15/05	13	22	**46%**	8%	**46%**	0%
12/13/05	24	198	8%	**21%**	**59%**	12%
1/17/06	22	**359**	**23%**	**36%**	**18%**	**23%**
2/21/06	3	4	100%	0%	0%	0%
3/20/06	5	12	100%	0%	0%	0%
4/26/06	9	24	**67%**	11%	0%	22%
5/15/06	9	28	22%	**56%**	0%	22%
6/21/06	10	18	20%	**30%**	10%	**40%**
7/24/06	24	130	**92%**	0%	4%	4%
8/22/06	21	50	**81%**	0%	0%	**19%**
9/27/06	15	28	**33%**	13%	**41%**	13%
10/30/06	24	**340**	**67%**	12%	**21%**	0%
11/15/06	24	**550**	**17%**	**17%**	**25%**	**41%**
12/18/06	13	118	**46%**	8%	8%	**38%**
1/24/07	17	68	**88%**	0%	0%	12%
2/20/07	11	36	9%	**46%**	18%	**27%**
3/19/07	23	**920**	4%	**26%**	**48%**	**22%**
5/30/07	4	14	75%	0%	25%	0%
6/18/07	3	6	0%	33%	67%	0%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.13 Summary of bacterial source tracking results from water samples collected in the James River impairment 2-JMS104.16.

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
7/19/05	24	60	**71%**	4%	0%	**25%**
8/23/05	3	4	67%	33%	0%	0%
9/20/05	9	14	**67%**	11%	0%	22%
10/18/05	17	36	**82%**	6%	6%	6%
11/15/05	11	36	**64%**	0%	0%	**36%**
12/13/05	24	206	12%	**59%**	**29%**	0%
1/17/06	23	**383**	4%	**62%**	**30%**	4%
2/21/06	10	18	**80%**	10%	0%	10%
3/20/06	12	18	**58%**	**25%**	17%	0%
4/26/06	20	56	**70%**	0%	5%	**25%**
5/15/06	23	**250**	9%	**47%**	**22%**	**22%**
6/21/06	4	8	0%	50%	0%	50%
7/24/06	23	94	**100%**	0%	0%	0%
8/22/06	24	78	**100%**	0%	0%	0%
9/27/06	24	**330**	**42%**	**21%**	4%	**33%**
10/30/06	24	170	**71%**	**21%**	8%	0%
11/15/06	23	**570**	**52%**	9%	9%	**30%**
12/18/06	17	82	**41%**	**24%**	0%	**35%**
2/20/07	13	136	**24%**	**38%**	0%	**38%**
3/19/07	24	**930**	8%	**38%**	**42%**	12%
5/30/07	11	48	**27%**	18%	**55%**	0%
6/18/07	2	10	100%	0%	0%	0%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.14 Summary of bacterial source tracking results from water samples collected in the James River impairment 2-JMS111.17.

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
7/19/05	24	48	**75%**	0%	8%	**17%**
8/23/05	23	60	**35%**	**39%**	9%	**17%**
9/20/05	24	207	**47%**	8%	12%	**33%**
10/18/05	17	52	**76%**	**18%**	0%	6%
11/15/05	10	26	**50%**	0%	10%	**40%**
12/13/05	23	147	**22%**	**17%**	**52%**	9%
1/10/06	5	18	40%	60%	0%	0%
3/14/06	14	24	**65%**	7%	7%	**21%**
4/17/06	11	14	**36%**	0%	0%	**64%**
5/10/06	23	60	**26%**	**65%**	9%	0%
6/7/06	19	180	**52%**	5%	**32%**	11%
7/17/06	20	46	**90%**	0%	5%	5%
8/2/06	9	50	22%	0%	**78%**	0%
9/5/06	20	**2,000**	**80%**	10%	10%	0%
10/3/06	24	68	**42%**	8%	4%	**46%**
11/7/06	4	8	100%	0%	0%	0%
12/5/06	4	14	25%	0%	25%	50%
2/14/07	24	130	**42%**	0%	**46%**	**12%**
3/19/07	24	**1,210**	**33%**	**22%**	**33%**	**12%**
6/4/07	24	120	**41%**	0%	**21%**	**38%**
6/12/07	24	82	**50%**	4%	**21%**	**25%**

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.15 Summary of bacterial source tracking results from water samples collected in the James River impairment 2-JMS111.47.

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
7/19/05	24	130	**100%**	0%	0%	0%
8/23/05	23	74	**57%**	**26%**	**17%**	0%
9/20/05	24	82	**54%**	0%	0%	**46%**
10/18/05	24	48	**84%**	12%	4%	0%
11/15/05	12	20	**49%**	17%	17%	17%
12/13/05	24	82	17%	4%	**75%**	4%
1/10/06	1	10	0%	0%	100%	0%
2/14/06	1	10	100%	0%	0%	0%
3/14/06	4	6	50%	0%	25%	25%
4/17/06	8	22	38%	25%	12%	25%
5/10/06	16	38	**38%**	**50%**	12%	0%
6/7/06	22	62	**18%**	**23%**	**59%**	0%
7/17/06	19	30	**100%**	0%	0%	0%
8/2/06	11	36	**36%**	0%	**64%**	0%
9/5/06	23	**890**	**92%**	4%	0%	4%
10/3/06	22	34	9%	0%	0%	**91%**
11/7/06	2	6	100%	0%	0%	0%
12/5/06	6	12	17%	0%	33%	50%
2/14/07	24	190	**42%**	4%	**33%**	**21%**
3/19/07	24	**1,080**	**21%**	**21%**	**37%**	**21%**
6/4/07	24	80	**25%**	**21%**	**54%**	0%
6/12/07	24	76	**51%**	4%	12%	**33%**

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.16 Summary of bacterial source tracking results from water samples collected in the James River impairment 2-JMS112.33.

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
7/19/05	24	66	**59%**	0%	8%	**33%**
8/23/05	16	32	**69%**	**19%**	6%	6%
9/20/05	16	40	**69%**	0%	12%	**19%**
10/18/05	17	40	**47%**	**29%**	12%	12%
11/15/05	13	24	**85%**	0%	15%	0%
12/13/05	24	90	8%	**17%**	**75%**	0%
1/10/06	3	6	34%	33%	33%	0%
2/14/06	5	14	80%	0%	20%	0%
3/14/06	6	8	50%	0%	17%	33%
4/17/06	18	48	**94%**	0%	0%	6%
5/10/06	24	68	**96%**	0%	4%	0%
6/7/06	23	36	**57%**	**26%**	**17%**	0%
7/17/06	17	30	**82%**	6%	12%	0%
8/2/06	11	34	**100%**	0%	0%	0%
9/5/06	17	**2,000**	**100%**	0%	0%	0%
10/3/06	24	120	17%	0%	0%	**83%**
11/7/06	4	6	100%	0%	0%	0%
12/5/06	8	16	88%	0%	12%	0%
2/14/07	24	**270**	**38%**	4%	**50%**	8%
3/19/07	23	**1,070**	4%	13%	**57%**	**26%**
6/4/07	24	74	0%	4%	**92%**	4%
6/12/07	24	72	**38%**	4%	**50%**	8%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.17 Summary of bacterial source tracking results from water samples collected in the James River impairment 2-JMS112.79.

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]:			
			Wildlife	Human	Livestock	Pet
7/19/05	24	98	**68%**	12%	8%	**12%**
8/23/05	24	80	**80%**	4%	8%	8%
9/20/05	24	74	**46%**	**46%**	0%	8%
10/18/05	14	58	**93%**	0%	0%	7%
11/15/05	3	6	34%	33%	0%	33%
12/13/05	24	94	8%	**17%**	**71%**	4%
1/10/06	6	12	0%	0%	17%	83%
2/14/06	1	2	0%	100%	0%	0%
3/14/06	11	14	**45%**	0%	0%	**55%**
4/17/06	14	28	**79%**	14%	7%	0%
5/10/06	21	48	**24%**	**57%**	**19%**	0%
6/7/06	22	48	**31%**	**23%**	**23%**	**23%**
7/17/06	20	46	**95%**	5%	0%	0%
8/2/06	18	114	**100%**	0%	0%	0%
9/5/06	24	**650**	**92%**	0%	0%	8%
10/3/06	24	72	**38%**	**41%**	0%	**21%**
11/7/06	4	8	75%	0%	25%	0%
12/5/06	4	10	25%	0%	25%	50%
2/14/07	24	**270**	**42%**	8%	**38%**	**12%**
3/19/07	24	**1,190**	**33%**	4%	**46%**	**17%**
6/4/07	21	78	**19%**	14%	**19%**	**48%**
6/12/07	21	46	**38%**	0%	0%	**62%**

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.18 Summary of bacterial source tracking results from water samples collected in the James River impairment 2-JMS115.29.

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
7/19/05	19	36	**37%**	**16%**	5%	**42%**
8/23/05	9	18	**67%**	22%	11%	0%
9/20/05	24	62	17%	**79%**	0%	4%
10/18/05	16	30	**56%**	**38%**	0%	6%
12/13/05	24	100	17%	**17%**	**37%**	**29%**
1/10/06	2	6	50%	0%	0%	50%
2/14/06	6	10	33%	50%	17%	0%
3/14/06	3	6	100%	0%	0%	0%
4/3/06	4	6	100%	0%	0%	0%
5/10/06	6	12	0%	67%	33%	0%
6/7/06	24	44	**21%**	**21%**	**33%**	**25%**
7/17/06	11	20	**73%**	9%	9%	9%
8/2/06	9	38	**89%**	0%	0%	11%
9/5/06	24	136	**92%**	0%	8%	0%
10/3/06	11	22	9%	**64%**	0%	**27%**
11/7/06	3	8	67%	33%	0%	0%
12/5/06	9	16	**44%**	0%	**56%**	0%
1/24/07	2	10	50%	0%	50%	0%
2/14/07	24	64	**33%**	4%	**51%**	**12%**
3/19/07	24	**1,160**	**21%**	12%	**55%**	**12%**
6/4/07	24	118	4%	**54%**	4%	**38%**
6/12/07	24	102	**38%**	0%	**62%**	0%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.19 Summary of bacterial source tracking results from water samples collected in the James River impairment 2-JMS117.35.

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
1/10/06	6	10	50%	33%	17%	0%
2/1/06	4	4	100%	0%	0%	0%
4/10/06	22	34	**95%**	5%	0%	0%
6/5/06	21	80	**100%**	0%	0%	0%
7/11/06	8	22	88%	12%	0%	0%
8/14/06	8	26	75%	25%	0%	0%
9/5/06	24	86	**46%**	**17%**	**25%**	**12%**
10/2/06	8	22	0%	0%	0%	100%
11/7/06	6	14	100%	0%	0%	0%
12/12/06	2	6	0%	0%	0%	100%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.20 Summary of bacterial source tracking results from water samples collected in the No Name Creek impairment (2-XSZ001.58).

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]: Wildlife	Human	Livestock	Pet
1/11/06	17	38	**40%**	**24%**	12%	**24%**
2/6/06	14	42	**51%**	**21%**	**21%**	7%
3/13/06	19	72	**58%**	**21%**	16%	5%
4/11/06	24	62	**17%**	**67%**	8%	8%
5/8/06	24	120	**67%**	**25%**	8%	0%
6/6/06	24	**530**	**84%**	8%	0%	8%
7/17/06	13	68	**54%**	15%	0%	**31%**
8/15/06	24	114	**42%**	8%	4%	**46%**
9/18/06	24	**550**	**63%**	8%	4%	**25%**
10/3/06	24	230	**100%**	0%	0%	0%
11/8/06	24	**1,050**	**51%**	12%	8%	**29%**
12/6/06	22	**500**	**81%**	5%	0%	14%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.21 Summary of bacterial source tracking results from water samples collected in the Powhite Creek impairment (2-PWT00.57).

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]:			
			Wildlife	Human	Livestock	Pet
1/10/06	1	2	0%	0%	0%	100%
2/14/06	4	4	50%	25%	25%	0%
3/14/06	24	120	**63%**	0%	4%	**33%**
4/17/06	24	52	**46%**	4%	4%	**46%**
5/10/06	24	**260**	**25%**	**59%**	12%	4%
6/7/06	12	36	**75%**	0%	8%	17%
7/17/06	2	10	50%	50%	0%	0%
9/5/06	24	**2,000**	**76%**	8%	4%	**12%**
10/3/06	24	100	**42%**	**16%**	0%	**42%**
11/7/06	24	42	**88%**	8%	0%	4%
12/5/06	24	72	**92%**	0%	4%	4%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.22 Summary of bacterial source tracking results from water samples collected in the Reedy Creek impairment 2-RDD000.19.

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]:			
			Wildlife	Human	Livestock	Pet
7/19/05	24	104	**55%**	8%	8%	**29%**
8/23/05	14	70	**51%**	**21%**	7%	**21%**
9/20/05	24	104	**33%**	**43%**	12%	**12%**
10/18/05	24	100	17%	**50%**	**25%**	8%
11/15/05	17	44	**29%**	0%	**18%**	**53%**
12/14/05	12	32	**42%**	8%	**42%**	8%
1/10/06	17	28	**47%**	**29%**	0%	**24%**
2/14/06	24	151	**50%**	**29%**	**17%**	4%
3/14/06	17	66	**35%**	6%	**41%**	**18%**
4/17/06	15	38	**93%**	0%	0%	7%
5/10/06	24	140	**67%**	**33%**	0%	0%
6/7/06	24	**320**	**76%**	12%	12%	0%
7/17/06	18	90	**61%**	**22%**	6%	11%
8/2/06	18	70	**100%**	0%	0%	0%
9/5/06	24	**2,000**	**96%**	0%	0%	4%
10/3/06	24	84	**50%**	4%	4%	**42%**
11/7/06	24	58	**83%**	0%	**17%**	0%
12/5/06	20	**360**	**60%**	**15%**	15%	10%
1/24/07	4	34	25%	50%	25%	0%
2/14/07	24	**720**	**38%**	8%	**33%**	**21%**
3/19/07	24	**510**	**25%**	**46%**	**29%**	0%
6/4/07	24	**1,680**	**29%**	0%	4%	**67%**
6/12/07	24	**340**	**55%**	8%	8%	**29%**

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.

Table 2.23 Isolate and percent weighted average proportions of *E. coli* originating from wildlife, human, livestock, and pet sources.

Stream Name	Station	Weighted Averages:				
		Wildlife	Human	Livestock	Pet	Anthropogenic (H+L+P)
Almond Creek	2-ALM000.42	65%	13%	9%	13%	35%
Bernards Creek	2-BOR001.73	44%	4%	32%	20%	56%
Falling Creek	2-FAC000.85	52%	13%	12%	23%	48%
Gillie Creek	2-GIL001.00	34%	20%	24%	22%	66%
Goode Creek	2-GOD000.77	69%	9%	7%	15%	31%
James River	2-JMS099.30	27%	20%	31%	22%	73%
James River	2-JMS104.16	31%	31%	22%	16%	69%
James River	2-JMS111.17	56%	14%	21%	9%	44%
James River	2-JMS111.47	52%	12%	22%	14%	48%
James River	2-JMS112.33	55%	5%	27%	13%	45%
James River	2-JMS112.79	53%	7%	26%	14%	47%
James River	2-JMS115.29	26%	16%	43%	13%	72%
James River	2-JMS117.35	73%	9%	10%	8%	27%
No Name Creek	2-XSZ001.58	66%	11%	4%	19%	33%
Powhite Creek	2-PWT00.57	69%	12%	5%	14%	31%
Reedy Creek	2-RDD000.19	57%	9%	10%	24%	43%

(H+L+P) = Human + Livestock + Pet

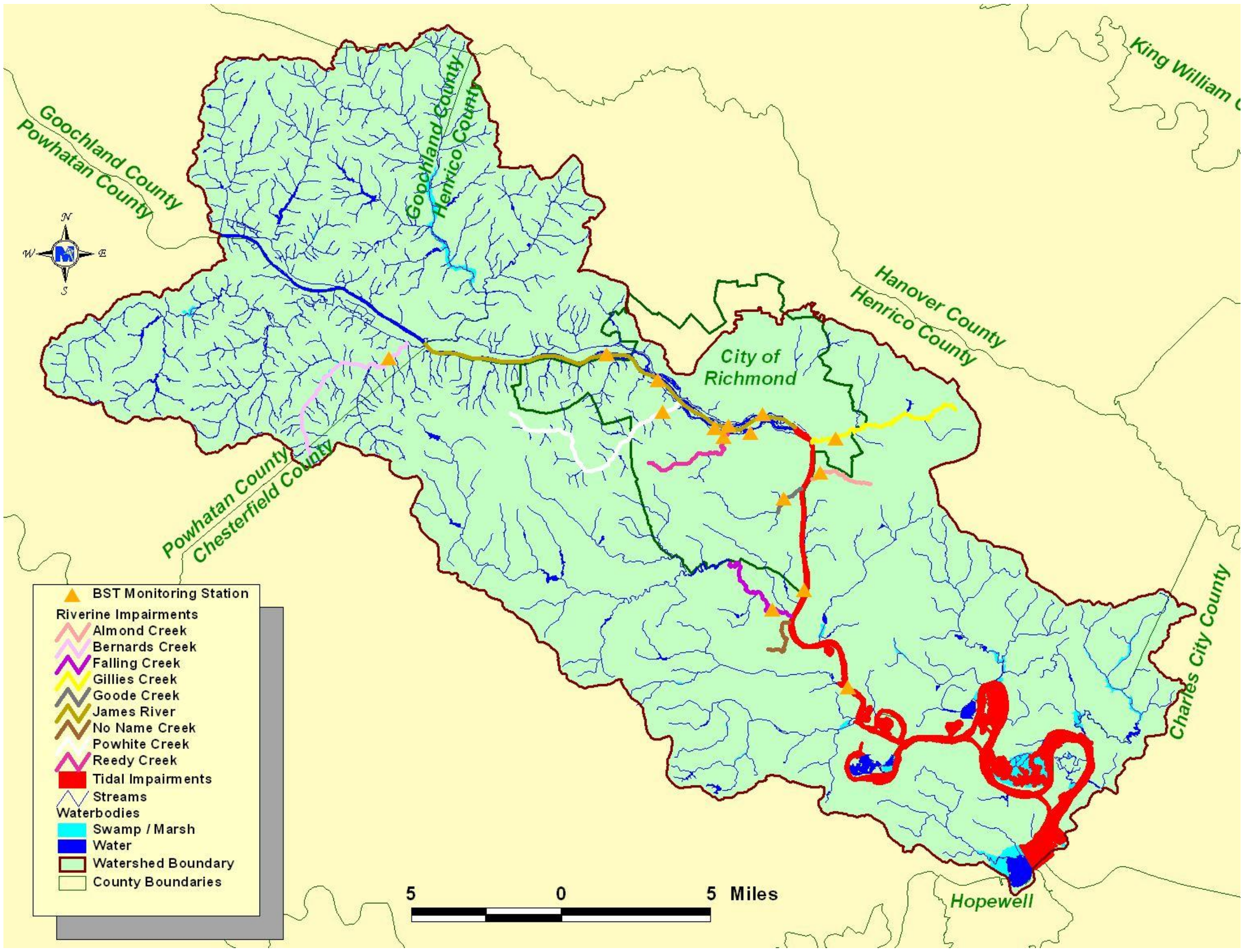

Figure 2.4 Location of BST water quality monitoring stations in the James River - City of Richmond area.

2.3.2 Trend and Seasonal Analyses

Trend and seasonal analyses were performed on precipitation, stream flow, and bacteria concentrations. A Seasonal Kendall Test, which ignores seasonal cycles, was used to examine long-term trends. This test improves the chances of finding existing trends in data that are likely to have seasonal patterns.

Total monthly precipitation measured at National Climatic Data Center (NCDC) station #447201 Richmond/Byrd Int. Airport was analyzed and no overall, long-term trend was found.

Significant trends were observed in fecal coliform data at VADEQ stations 2-ALM000.42, 2-JMS117.35, 2-JMS104.16, 2-JMS099.30, and 2-JMS087.01 (Appendix B, Table B.1). The trend at station 2-JMS117.35 was positive indicating a statistically significant increase in fecal coliform concentrations over time, while the other stations showed negative trends indicating statistically significant decreases in fecal coliform concentrations. The other stations with adequate data showed no trends. There was not enough data to perform the trend analysis on *E. coli* or *enterococci* data.

Figure B.58 in Appendix B shows that generally the fecal coliform concentrations in the James River increase upon entering the City of Richmond and decrease upon exiting the city.

A seasonal analysis of precipitation and fecal coliform concentration data were conducted using the Mood’s Median Test (Minitab, 1995). This test was used to compare median values of precipitation and fecal coliform concentrations in each month. Significant differences between months within years were reported.

Mood’s Median tests were preformed to show seasonality effects in the James River – City of Richmond data. Significant seasonality effects were found at the precipitation station. Differences in mean monthly precipitation are indicated in Table B.45 (Appendix B). Precipitation values, at a given station, in months with the same median group letter are not significantly different from each other at a 95% significance level.

Three VADEQ stations showed statistically significant seasonality differences in fecal coliform values: 2-JMS117.35, 2-JMS087.01, and 2-PWT000.57 (Appendix B, Tables B.2 through B.4). There was not enough data to perform the Moods Median analysis on *E. coli* or *enterococci* data.

3. SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal bacteria in the James River – City of Richmond study area. The source assessment was used as the basis of model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local management agencies. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and nonpoint sections. The representation of the following sources in the model is discussed in Chapter 4.

3.1 Watershed Characterization

The National Land Cover Database 2001 (NLCD) produced cooperatively between the U.S. Geological Survey (USGS) and U.S. Environmental Protection Agency (EPA) was utilized for this study. The collaborative effort to produce this dataset is part of a Multi-Resolution Land Characteristics (MRLC) Consortium project led by four U.S. government agencies: EPA, USGS, the Department of the Interior National Biological Service (NBS), and the National Oceanic and Atmospheric Administration (NOAA). Using 30-meter resolution Landsat 7 Thematic Mapper (TM) satellite images taken between 1999 and 2001, digital land use coverage was developed identifying up to 29 possible land use types. Classification, interpretation, and verification of the land cover dataset involved several data sources when available including: aerial photography; soils data; population and housing density data; state or regional land cover data sets; USGS land use and land cover (LUDA) data; 3-arc second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief; and National Wetlands Inventory (NWI) data. Approximate acreages and land use proportions for the James River – City of Richmond study area are given in Table 3.1 and shown in Figure 3.1. More details about land uses are in Section 4.2.2.

Table 3.1 Contributing land use acreage (2001) in the James River – City of Richmond study area.

Barren	Commercial	Crop	Forest	LAX	LMIR	Open Space	Pasture/Hay	Water	Wetland	Total
1,923	4,973	11,451	119,905	677	49,678	40,455	37,214	11,250	11,944	289,470

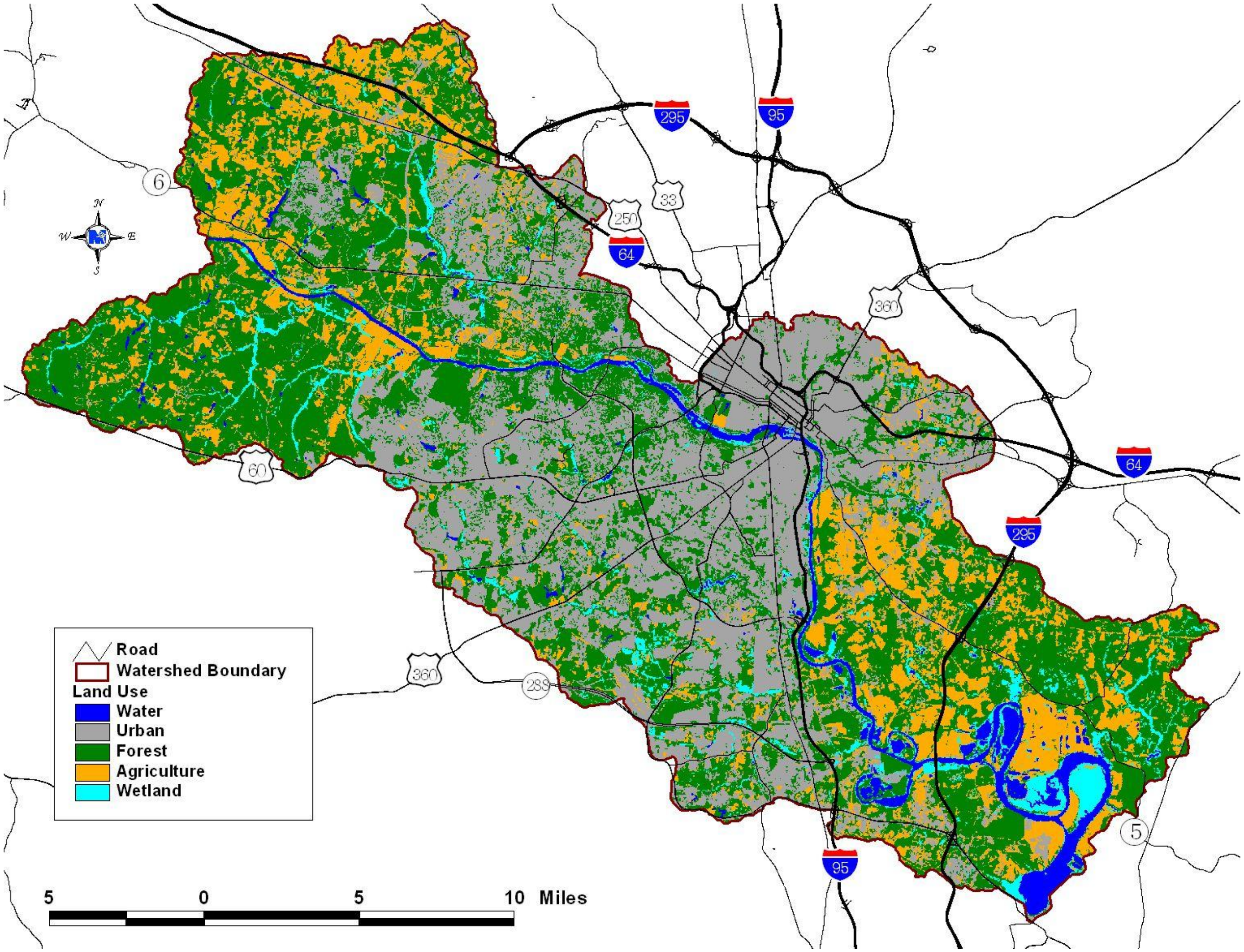

Figure 3.1 Land uses in the James River – City of Richmond area watershed.

Goochland, Powhatan, Henrico, and Chesterfield Counties and Richmond City are home to numerous species of wildlife, including mammals (*e.g.,* beaver, raccoon, white-tailed deer) and birds (*e.g.,* wood duck, wild turkey, geese) (VDGIF, 2006) (Table 3.2).

For the period from 1948 to 2005, the Richmond International Airport (station 447201) received average annual precipitation of approximately 43.65 inches, with 56% of the precipitation occurring during the May through October growing season (SERCC, 2006). Average annual snowfall is 13.5 inches, with the highest snowfall occurring during January (SERCC, 2006). Average annual daily temperature is 58.1 ºF. The highest average daily temperature of 88.7 ºF occurs in July, while the lowest average daily temperature of 27.6 ºF occurs in January (SERCC, 2006).

3.2 Assessment of Permitted Sources

Thirty-three (33) point sources, some with multiple outfalls, are permitted to discharge to surface water bodies in the James River – City of Richmond study area through the Virginia Pollutant Discharge Elimination System (VPDES). These are listed in Table 3.2, which is broken into two tables. The use of “Trib” in this table refers to a tributary. The first 12 VPDES permits shown are permitted for fecal bacteria control. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 ml. Currently, these permitted discharges are expected not to exceed the 126 cfu/100mL *E. coli* standard. One method for achieving this goal is chlorination. Chlorine is added to the discharge stream at levels intended to kill pathogens. The monitoring method for ensuring the goal is to measure the concentration of total residual chlorine (TRC) in the effluent. If the concentration is high enough, pathogen concentrations (including fecal coliform concentrations) are considered reduced to acceptable levels. Typically, if minimum TRC levels are met, bacteria concentrations are reduced to levels well below the standard. The remaining 21 VPDES permits are not permitted for fecal bacteria control, but they do discharge water to the streams.

Table 3.3 shows the single family home permits within the James River – City of Richmond study area. These permits allow treated residential wastewater to be discharged to surface waters. All of these permits discharge water and bacteria to the streams.

Table 3.4 summarizes data from VPDES Confined Animal Feeding Operations (CAFO) and from Virginia Pollution Abatement (VPA) facilities. These two permitted sources do not have direct discharges to waterways but runoff from the area could contain fecal bacteria.

Table 3.5 shows the Municipal Separate Storm Sewer System (MS4) permits. These are areas of land with stormwater runoff collection that discharge to surface waters. The land area within these permit boundaries has bacteria from land-based sources (pet, human, wildlife) which can be present in the runoff.

Table 3.6 shows the surface water withdrawal permits for the James River – City of Richmond study area. These operations remove water from the James River, Glenwood Pond and Lake Meadowbrook.

Table 3.7 shows the groundwater withdrawal permits for the James River – City of Richmond study area. These operations remove water by pumping from different underground wells.

In a portion of the City of Richmond, the sanitary sewer also collects stormwater runoff from areas adjacent to the James River and stream flow from some tributaries. This type of system is referred to as a combined sewer system (CSS). The amount of runoff and stream flow from these areas is dependent on rainfall. On a dry flow day (no recent rainfall) the James River Wastewater Treatment Plant (WWTP) treats this flow. During heavy rainfall the system may fill to capacity and the James River Wastewater Treatment Plant (WWTP) cannot treat the entire volume; therefore overflows occur. These combined sewer overflows (CSOs) are a part of VPDES permit number VA0063177. Table 3.8 summarizes the current CSOs within the James River – City of Richmond study area. Appendix F contains Tables extracted from the City's 2008 Annula CSO Report. These tables indicate the frequency and volume of overflows modeled for 2008, as well as, the size of storm events initiating the overflow events. The City of Richmond has an ongoing CSO program to reduce the number of overflows at each location each year, upgrade the wastewater treatment plant, and pre-treat the combined water (City of Richmond and Greeley and Hansen, 2006). Figure 3.2 shows the locations of these CSOs.

Table 3.2 Summary of VPDES permitted point sources in the James River – City of Richmond study area.

Permit	Receiving Stream(s)	Facility Name	Outfall Number(s)	Permitted for Fecal Bacteria Control
VA0003077	James River (tidal)	DuPont Teijin Films	001, 002, 003, 004, 101, 102	Yes - 001, 102
VA0024163	James River (not impaired)	Mary Mother of the Church Abbey WWTP	001	Yes
VA0024996	James River (tidal)	Falling Creek WWTP	001, 002, 003, S01, SP1	Yes - 001
VA0026557	James River (tidal)	Philip Morris USA Incorporated - Park 500	001	Yes
VA0027910	Trib to Little River to James River (not impaired)	Manakin Farms Inc Lagoon	001	Yes
VA0028622	James River (tidal)	Harbour East Village WWTP	001	Yes
VA0060194	Proctors Creek	Proctors Creek WWTP	001	Yes
VA0063177	James River (lower and tidal), Gillie Creek, and Tribs	Richmond WWTP	001 – 007, 009 – 021, 024 – 026, 028, 031, 033 – 035, 039, 040	Yes - 001
VA0063649	Trib to Tuckahoe Creek	Richmond Country Club WWTP	001	Yes
VA0063690	James River (tidal)	Henrico County WWTP	001, S01, SP1	Yes - 001
VA0066494	UT to Proctors Creek	Youngs Mobile Home Park	001	Yes
VA0090727	Dutoy Creek	Dutoy Creek WWTP	001, S01, SP1	Yes - 001

Table 3.2 Summary of VPDES permitted point sources in the James River – City of Richmond study area (cont.).

Permit	Receiving Stream(s)	Facility Name	Outfall Number(s)	Permitted for Fecal Bacteria Control
VA0002780	James River (tidal)	The Sustainability Park LLC	001	No [1]
VA0004146	James River	Dominion Chesterfield Power Station	001 - 005	No
VA0088153	UT to Redwater Creek	Trans Industrial Incorporated	001	No
VA0004669	James River (tidal)	E I du Pont de Nemours and Company - Spruance Plt	001, 002, 003, 101, 102, 103	No
VA0004880	James River (tidal)	Du Pont De Nemours E I and Co Inc James River Pl	001, 002	No
VA0005312	James River (tidal)	Honeywell Nylon LLC - Chesterfield	001, 002	No
VA0005720	Trib to James River (tidal)	Motiva Enterprises LLC - Richmond Terminal-Texaco	001, 002, 003	No
VA0029165	Almond Creek	Kinder Morgan Operating LP - Bickerstaff Road	001	No
VA0054291	James River (tidal)	IMTT - Virginia East	001, 002	No
VA0054330	Trib to James River (tidal)	Hammaker East	001	No
VA0055409	Almond Creek	IMTT – Virginia West	001	No
VA0058378	James River (tidal)	Kinder Morgan Southeast Terminals LLC - Richmond 2	001	No
VA0084565	UT to Branch Creek	Powhatan Courthouse Water Treatment Plant	001	No
VA0085499	James River (tidal)	Spruance Genco LLC	001	No
VA0086151	Trib to James River (tidal)	Kinder Morgan Operating LP – Deepwater Terminal	001, 002	No
VA0087734	Trib to Falling Creek	VEPCO Maintenance and Supply Center	001	No
VA0090964	Trib to Proctors Creek	Rehrig International Incorporated	001, 002	No
VA0091154	Trib to Bailey Creek	Camp Holly Springs	001	No
VA0091197	Trib to Deep Run	Henrico County Water Treatment Plant	001	No
VA0091499	Trib to Almond Creek	BFI Old Dominion Landfill	003, 005, 006, 007	No
VA0091642	Kingsland Creek	Defense Supply Center Richmond	001 - 010, 012, 06A	No

[1] Facility currently operating at Tier 1 – industrial discharge, which is not believed to contribute bacteria. Upon the issuance of a Certificate To Operate (CTO) for Tiers 2 & 3, a municipal discharge of 3.0 MGD will apply.

Table 3.3 Single family home permits in the James River – City of Richmond study area.

Permit	Receiving Stream	Facility Name
VAG404078	James River	Private Residence
VAG404208	James River	Henricus Historical Park
VAG404145	Cornelius Creek	Crowders Service Center
VAG404175	Cornelius Creek	Pocahontas Parkway Toll Facility
VAG404201	Trib to James River	Private Residence
VAG404223	James River	Private Residence
VAG404224	James River	Private Residence
VAG404238	Trib to Falling Creek	Private Residence
VAG404029	James River	Private Residence
VAG404033	James River	Private Residence
VAG404219	Trib to Powhite Creek	Private Residence
VAG404247	James River	Private Residence
VAG404248	UT to James River	Private Residence

Table 3.4 CAFO permits in the James River – City of Richmond study area.

Permit Number	Facility Name	Water Body	Type	Adjacent Receiving Stream
VPG140049	Alvis Farms LLC	VAP-H39R	Poultry	Dover Creek/U.T.
VPG100081	Alvis Farms LLC	VAP-H39R	Poultry	Dover Creek/U.T.

Table 3.5 Permits for MS4s in the James River – City of Richmond study area.

Permit	Phase	Facility Name
VAR040001	Phase II	Defense Supply Center - Richmond
VAR040005	Phase II	Richmond City
VAR040115	Phase II	VDOT - Virginia
VA0088609	Phase I	Chesterfield County
VA0088607	Phase I	Henrico County DPW
VAR040110	Phase II	John Tyler Community College
VAR040116	Phase II	Hunter Holmes McGuire VA Hospital

Table 3.6 Permitted surface water withdrawals in the James River – City of Richmond study area.

Source	Owner Name	System
James River	Dupont E I De Nemours & Co	James River Plant
James River	Dupont E I De Nemours & Co	Spruance Plant
James River	Dupont E I De Nemours & Co	James River Plant
James River	Dominion Chesterfield Power Station	Dominion Virginia Power*
Glenwood Pond	Glenwood Golf Club	Glenwood Golf Course
Lake Meadowbrook	Meadowbrook Country Club	Meadowbrook Country Club
James River	Vulcon Construction Materials	Richmond Quarry
James River	Henrico County	Henrico Co WTF
Blackman Creek	Westham Golf Club	Westham Golf Club
Michaulk Creek	VA State Golf Assoc.	VA State Golf Assoc.
James River	City of Richmond	City of Richmond Water Treatment Facility*

*Amounts not used in hydrological modeling of watershed

Table 3.7 Permitted groundwater withdrawals in the James River – City of Richmond study area.

Source	Owner Name	System
50 Remediation Wells	Dupont E I De Nemours & Co	Spruance Plant
18 Remediation Wells	The Shops at White Oaks	The Shops at White Oaks

Table 3.8 Combined Sewer Overflows (CSOs) discharge locations currently included in permit #VA0063177.

Outfall Number	Outfall Name	Location
002	Orleans Street	Orleans and Main Streets
003	Nicholson Street	Nicholson and Main Streets
004	Bloody Run	Main Street, southeast of 32nd Street
005	Peach Street	South of intersection of Peach and Dock Streets
006	Shockoe Creek	Between Mayo's Bridge and 17th St.
007	Byrd Street	Byrd Street, between 12th and 13th Streets
009	7th Street	7th and Bragg Streets
010	Gambles Hill	Tredegar Street, West of 7th St.
011	Park Hydro Station	Tredegar Street, West of Lee Bridge
012	Hilton Street	Southwest of intersection of Hilton and Salem Streets
013	Maury Street	Maury and Brander Streets
014	Stockton Street	Stockton and Bedford Streets
015	Canoe Run	Next to Southern Railway Line, north of Riverside Drive and 22nd Street
016	Woodland Heights	Next to Southern Railway Line, north of Riverside Drive and 26th Street
017	Reedy Creek	Next to Southern Railway Line, approx. north of Riverside Drive
018	42nd Street	Next to Southern Railway Line, north of Riverside Drive and 42nd Street
019	Hampton Street and Colorado	New York Avenue, between Hampton Street and Meadow Avenue
020	McCloy Street	McCloy Street
021	Gordon Avenue	Brander Street, East of I-95
024	White and Varina Streets	Gilley and Varina Streets
025	Briel Street and Gillie Creek	Briel Street and Gillie Creek
026	1250 feet East of Government Road	1250 ft. east of Government Road and Southern Railway Line
028	800 feet North of Nicholson Street	550 ft. north of Nicholson Street on Williamsburg Road
031	Oakwood Cemetery	Oakwood Cemetery
033	Shields Lake	Park Drive and Shields Lake
034	19th and Dock Streets	19th and Dock Streets
035	25th and Dock Streets	25th and Dock Streets
039	550 feet downstream from Government Road	550 ft. downstream from Gillie Creek and Government Road
040	CSO-1 Outlet	1250 ft. downstream of the Manchester Bridge

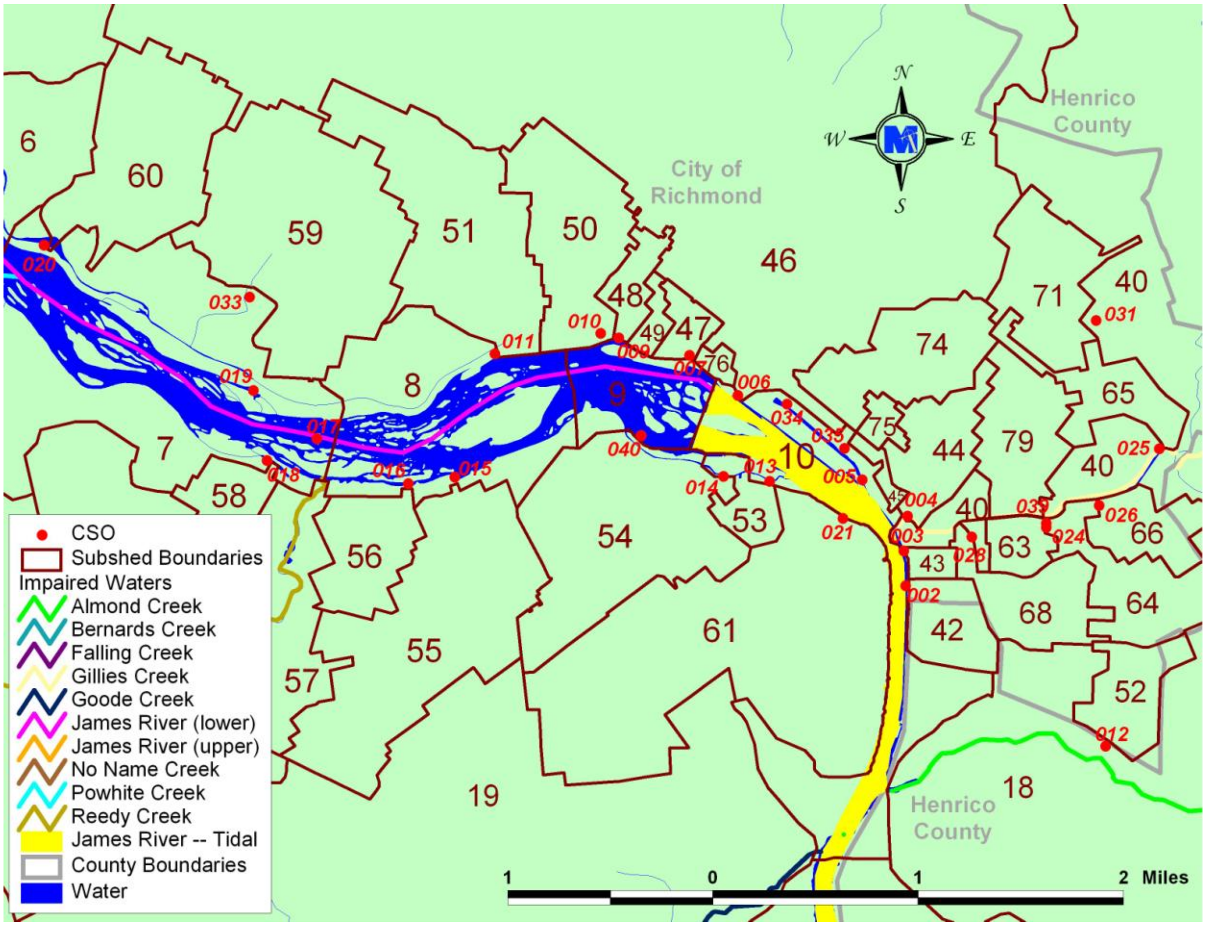

Figure 3.2 Combined Sewer Overflows (CSOs) discharge locations currently included in permit #VA0063177 and the modeling subwatersheds (described in Section 4.2.1).

3.3 Assessment of Nonpoint Sources

In the James River – City of Richmond study area, both urban and rural nonpoint sources of fecal bacteria were considered. Sources include permitted waste treatment facilities, combined sewer overflows, direct untreated human waste (straight pipes), non-permitted sewer overflows, leaking sewer lines, failing septic systems, land-application of waste (livestock and biosolids), wildlife, and pets. Sources were identified and enumerated. MapTech previously collected samples of fecal bacteria sources (*i.e.,* wildlife, livestock, pets, and human waste) and enumerated the density of fecal coliform bacteria to support the modeling process and to expand the database of known fecal coliform sources for purposes of bacterial source tracking (Section 2.4.2.1). Where appropriate, spatial distribution of sources was also determined.

3.3.1 Private Residential Sewage Treatment

Population, housing units, and type of sewage treatment from U.S. Census Bureau were calculated using GIS (Table 3.9). In the U.S. Census questionnaires, housing occupants were asked which type of sewage disposal existed. Houses can be connected to a public sanitary sewer, a septic tank, or a cesspool, or the sewage is disposed of in some other way. The Census category "Other Means" includes the houses that dispose of sewage other than by public sanitary sewer or a private septic system. The houses included in this category are assumed to be disposing of sewage via a pit-privy or through the use of a straight pipe (direct stream outfall).

Sanitary sewers are piping systems designed to collect wastewater from individual homes and businesses and carry it to a wastewater treatment plant. Sewer systems are designed to carry a specific "peak flow" volume of wastewater to the treatment plant. Within this design parameter, sanitary collection systems are not expected to overflow, surcharge or otherwise release sewage before their waste load is successfully delivered to the wastewater treatment plant.

When the flow of wastewater exceeds the design capacity or the capacity is reduced by a blockage, the collection system will "back up" and sewage discharges through the nearest escape location. These discharges into the environment are called overflows. Wastewater can also enter the environment through exfiltration caused by line cracks, joint gaps, or breaks in the piping system.

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and a drainage field. Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal bacteria to surface waters.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation, the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. A survey of septic pump-out contractors previously performed by MapTech showed that failures were more likely to occur in the winter-spring months than in the summer-fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed in the yard.

MapTech previously sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 ml (MapTech, 2001). An average fecal coliform density for human waste of 13,000,000 cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

Table 3.9 Estimated population, housing units and residential sewage disposal methods currently in the James River – City of Richmond study area.

Impaired Segment	Population	Housing Units	Sanitary Sewer	Septic Systems	Other *
Almond Creek	8,089	3,262	2,962	296	5
Bernards Creek	6,814	2,266	1,058	1,201	7
Falling Creek	121,558	45,811	40,060	5,705	47
Gillie Creek	41,001	17,536	16,937	556	44
Goode Creek	17,312	7,758	7,675	74	10
James River (lower)	198,507	86,090	75,545	10,339	206
James River (tidal)	516,039	213,833	186,662	26,670	501
No Name Creek	1,962	869	760	101	7
Powhite Creek	24,618	11,053	9,737	1,288	27
Reedy Creek	18,576	9,311	9,162	118	31

* Houses with sewage disposal systems other than sanitary sewer and septic systems.

3.3.2 Biosolids

Between 1997 and 2001, biosolids were applied to several areas within the James River – City of Richmond study area (Table 3.10). Biosolids are the treated solids remaining after human sewage has been treated at a wastewater treatment facility. The total amount of biosolids applied was 11,702 dry tons. The application of biosolids to agricultural lands is strictly regulated in Virginia (VDH, 1997). The task of regulating biosolids application in Virginia was transferred in 2007 from the Department of Health to the Department of Environmental Quality. Biosolids are required to be spread according to sound agronomic requirements with consideration for topography and hydrology. Class B biosolids may not have a fecal coliform density greater than 1,995,262 cfu/g (total solids). Application rates must be limited to a maximum of 15 dry tons/acre per three-year period.

Table 3.10 Application of dry biosolids within the James River – City of Richmond study area.

	Net Dry Tons				
Impaired Segment	**1998**	**1999**	**2000**	**2001**	**Total**
Almond Creek	0	0	0	0	0
Bernards Creek	0	0	0	1,098	1,098
Falling Creek	0	0	0	0	0
Gillie Creek	0	0	0	0	0
Goode Creek	0	0	0	0	0
James River (lower)	0	0	0	84	84
James River (tidal)	1,002	3,470	2,888	3,161	10,520
No Name Creek	0	0	0	0	0
Powhite Creek	0	0	0	0	0
Reedy Creek	0	0	0	0	0
Total	**1,002**	**3,470**	**2,888**	**4,343**	**11,702**

3.3.3 Pets

Among pets, cats and dogs are the predominant contributors of fecal bacteria in the James River – City of Richmond and were the only pets considered in this analysis. Cat and dog populations were derived from the American Veterinary Medical Association Center for Information Management demographics in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was previously measured. Fecal coliform density for dogs and cats was previously measured from samples collected by MapTech. A summary of the data collected is given in Table 3.11. Table 3.12 lists the domestic animal populations for impairments in the James River – City of Richmond.

Table 3.11 Domestic animal population density, waste load, and fecal coliform density.

Source	Population Density (an/house)	Waste load (g/an-day)	FC Density (cfu/g)
Dog	0.534	450	480,000
Cat	0.598	19.4	9

Table 3.12 Estimated current domestic animal populations in the James River – City of Richmond study area.

Impaired Segment	Dogs	Cats
Almond Creek	1,742	1,951
Bernards Creek	1,210	1,355
Falling Creek	24,463	27,395
Gillie Creek	9,364	10,487
Goode Creek	4,143	4,639
James River (lower)	45,972	51,482
James River (tidal)	114,187	127,872
No Name Creek	464	519
Powhite Creek	5,902	6,610
Reedy Creek	4,972	5,568

3.3.4 Livestock

The predominant types of livestock in the James River – City of Richmond study area are beef cattle and horses although all types of livestock identified were considered in modeling the watersheds. Operations range from small to large in size, including two operations permitted under either VPA or CAFO regulations. Table 3.4 gives a summary of these permitted operations in the drainage area of impaired streams in the James River – City of Richmond study area. Table 3.13 gives a summary of livestock populations in the James River – City of Richmond study area for 2006, organized by impairment. Animal populations were based on communication with VADEQ, Virginia Cooperative Extension Service (VCE), Virginia Department of Conservation and Recreation (VADCR), Natural Resources Conservation Service (NRCS), Henricopolis Soil and Water Conservation District (PSWCD), James River SWCD (JRSWCD), Monacan Soil and Water Conservation District (MSWCD), Farm Services Agency, local extension agents, watershed visits, and verbal communication with citizens at the first public meeting.

Table 3.13 Estimated livestock populations for 2006 in the James River – City of Richmond study area.

Impaired Segment	Beef Adult	Beef Calves	Dairy Calves	Dairy Dry	Dairy Milkers	Hogs	Horse	Sheep	Deer Zoo	Bison Zoo
Almond Creek	28	27	0	0	0	1	30	6	0	0
Bernards Creek	86	60	9	9	19	5	77	4	0	0
Falling Creek	113	70	0	0	0	31	188	10	0	0
Gillie Creek	40	38	0	0	0	2	42	9	0	0
Goode Creek	0	0	0	0	0	0	0	0	0	0
James River (lower)	1,738	1,626	170	170	343	45	1,329	108	29	3
James River (tidal)	2,538	2,275	170	170	347	149	2,324	254	29	3
No Name Creek	0	0	0	0	0	0	0	0	0	0
Powhite Creek	12	7	0	0	0	3	20	1	0	0
Reedy Creek	0	0	0	0	0	0	0	0	0	0
Watershed Total	**2,538**	**2,275**	**170**	**170**	**347**	**149**	**2,324**	**254**	**29**	**3**

Values of fecal coliform density of livestock sources were based on sampling previously performed by MapTech (MapTech, 1999a). Reported manure production rates for livestock were taken from the American Society of Agricultural Engineers (1998). A summary of fecal coliform density values and manure production rates is presented in Table 3.14.

Table 3.14 Average fecal coliform densities and waste loads associated with livestock.

Type	Waste Load (lb/d/an)	Fecal Coliform Density (cfu/g)	Waste Storage Die-off factor
Beef stocker (850 lb)	51.0	101,000	NA
Beef calf (350 lb)	21.0	101,000	NA
Dairy milker (1,400 lb)	120.4	271,329	0.5
Dairy heifer (850 lb)	70.0	271,329	0.25
Dairy calf (350 lb)	29.0	271,329	0.5
Hog (135 lb)	11.3	400,000	0.8
Hog Lagoon	N/A	95,300[1]	NA
Horse (1,000 lb)	51.0	94,000	NA
Sheep (60 lb)	2.4	43,000	NA
Goat (140 lb)	5.7	15,000	NA
Poultry (1 lb):			
Broiler	0.17	586,000	0.5
Layer	0.26	586,000	0.5

[1]units are cfu/100ml

Fecal coliform produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.,* pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Table 3.15 shows the average percentage of collected livestock waste that is applied throughout the year. Second, grazing livestock deposit manure directly on the land where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage ways or streams.

Table 3.15 Average percentage of collected livestock waste applied throughout year.

Month	Applied % of Total		Land use
	Dairy	Beef	
January	2.00	4.00	Cropland
February	2.00	4.00	Cropland
March	20.00	12.00	Cropland
April	20.00	12.00	Cropland
May	5.00	12.00	Cropland
June	2.00	8.00	Pasture
July	2.00	8.00	Pasture
August	2.00	8.00	Pasture
September	21.00	12.00	Cropland
October	20.00	12.00	Cropland
November	2.00	4.00	Cropland
December	2.00	4.00	Cropland

Some livestock were expected to deposit a portion of waste on land areas. The percentage of time spent on pasture for dairy and beef cattle was estimated based on projects in other areas of the James River basin. Horses, sheep, and hogs were assumed to be in pasture 100% of the time.

It was assumed that beef cattle were expected to make a significant contribution through direct deposition with access to flowing water. For areas where direct deposition by cattle is assumed, the average amount of time spent by dairy and beef cattle in stream access areas for each month is given in Tables 3.16 and Table 3.17.

Table 3.16 Average time dry cows and replacement heifers spend in different areas per day.

Month	Pasture (hr)	Stream Access (hr)	Loafing Lot (hr)
January	23.3	0.7	0
February	23.3	0.7	0
March	22.6	1.4	0
April	21.8	2.2	0
May	21.8	2.2	0
June	21.1	2.9	0
July	21.1	2.9	0
August	21.1	2.9	0
September	21.8	2.2	0
October	22.6	1.4	0
November	22.6	1.4	0
December	23.3	0.7	0

Table 3.17 Average time beef cows not confined in feedlots spend in pasture and stream access areas per day.

Month	Pasture (hr)	Stream Access (hr)
January	23.3	0.7
February	23.3	0.7
March	23.0	1.0
April	22.6	1.4
May	22.6	1.4
June	22.3	1.7
July	22.3	1.7
August	22.3	1.7
September	22.6	1.4
October	23.0	1.0
November	23.0	1.0
December	23.3	0.7

3.3.5 Wildlife

The predominant wildlife species in the James River – City of Richmond watershed were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), United States Fish and Wildlife Service (FWS), citizens from the watershed, and source sampling. Population densities were calculated from data provided by VDGIF and FWS, and are listed in Table 3.18 (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Norman, 2004; Raftovich, 2004; Rose and Cranford, 1987).

Table 3.18 Wildlife population densities for the James River – City of Richmond study area.

Deer (an/ac of habitat)	Turkey (an/ac of habitat)	Goose (an/ac of habitat)	Duck (an/ac of habitat)	Muskrat (an/ac of habitat)	Raccoon (an/ac of habitat)	Beaver (an/mi of stream)
0.0279	0.0087	0.0198	0.0333	0.6115	0.0226	4.0

The numbers of animals estimated to be in the James River – City of Richmond watershed are reported in Table 3.19. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996, and Yagow, 1999b).

Table 3.19 Estimated wildlife populations in the James River – City of Richmond study area.

Impaired Segment	Raccoon	Muskrat	Deer	Goose	Turkey	Duck	Beaver
Almond Creek	59	96	72	3	12	5	9
Bernards Creek	254	706	292	22	80	38	67
Falling Creek	662	2,162	690	70	150	118	203
Gillie Creek	150	332	174	10	32	18	1
Goode Creek	51	153	41	5	6	8	16
James River (lower)	2,576	8,805	3,148	279	791	479	753
James River (tidal)	5,472	21,090	6,735	677	1,567	1,148	1,697
No Name Creek	20	33	17	1	3	2	3
Powhite Creek	137	388	114	12	26	21	36
Reedy Creek	48	88	34	3	7	5	6

The fecal coliform density of beaver waste was taken from sampling done for the Mountain Run TMDL development (Yagow, 1999a). Percentage of time spent in stream access areas and percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling. Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream) are reported in Table 3.20.

Table 3.20 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife.

Animal Type	Fecal Coliform Density (cfu/g)	Portion of Day in Stream Access Areas (%)
Raccoon	2,100,000	5
Muskrat	1,900,000	90
Beaver	1,000	100
Deer	380,000	5
Turkey	1,332	5
Goose	250,000	50
Duck	3,500	75

Table 3.21 summarizes the habitat and fecal production information that was obtained. Where available, fecal coliform densities were based on sampling of wildlife scat performed by MapTech. The only value that was not obtained from MapTech sampling in the watershed was for beaver.

Table 3.21 Wildlife fecal production rates and habitat.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	Primary = region within 600 ft of perennial streams Secondary = region between 601 and 7,920 ft from perennial streams Infrequent/Seldom = rest of watershed area including waterbodies (lakes, ponds)
Muskrat	100	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Beaver[1]	200	Primary = Perennial streams. Generally flat slope regions (slow moving water), food sources nearby (corn, forest, younger trees) Infrequent/Seldom = rest of the watershed area
Deer	772	Primary = forested, harvested forest land, orchards, grazed woodland, urban grassland, cropland, pasture, wetlands, transitional land Secondary = low density residential, medium density residential Infrequent/Seldom = remaining landuse areas
Turkey[2]	320	Primary = forested, harvested forest land, grazed woodland, orchards, wetlands, transitional land Secondary = cropland, pasture Infrequent/Seldom = remaining landuse areas
Goose[3]	225	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area
Mallard (Duck)	150	Primary = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies Secondary = region between 67 and 308 ft from perennial streams, and waterbodies Infrequent/Seldom = rest of the watershed area

[1] Beaver waste load was calculated as twice that of muskrat, based on field observations.
[2] Waste load for domestic turkey (ASAE, 1998).
[3] Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003)

4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of TMDLs in the James River – Richmond area, the relationship was defined through computer modeling based on data collected throughout the watersheds. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. There are five basic steps in the development and use of a water quality model: model selection, source assessment, selection of a representative modeling period, model calibration, model validation, and model simulation.

Model selection involves identifying an approved model that is capable of simulating the pollutants of interest with the available data. Source assessment involves identifying and quantifying the potential sources of pollutants in the watershed. Selection of a representative period involves the identification of a time period that accounts for critical conditions associated with all potential sources within the watershed. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Validation is the process of comparing modeled data to observed data during a period other than that used for calibration, with the intent of assessing the capability of the model in hydrologic conditions other than those used during calibration. During validation, no adjustments are made to model parameters. Once a suitable model is constructed, the model is then used to predict the effects of current loadings and potential management practices on water quality. In this section, the selection of modeling tools, source assessment, selection of a representative period, calibration/validation, and model application are discussed.

4.1 Modeling Framework Selection

The James River – City of Richmond study area contains both riverine and tidally influenced systems, and thus requires a very robust and versatile modeling platform. The

James River (tidal) impaired segment (VAP-G01E-01) is a tidally influenced river system. This river segment is not estuarine (fresh and salt water mixed), but freshwater is pushed upstream and pulled downstream by the tides from the Chesapeake Bay and Atlantic Ocean. This water body is riverine in structure and is known to receive substantial flow inputs from storm water runoff.

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate riverine streamflow, overland runoff inputs into the tidal model, and existing conditions, and to perform TMDL allocations in non-tidal areas. CE-QUAL-W2 (Army Corps of Engineers, 2003) was chosen as the model to simulate the James River (tidal) impaired segment and to perform TMDL allocations in this segment.

4.1.1 Modeling Free Flowing Streams

The HSPF model simulates a watershed by dividing it up into a network of stream segments (referred to in the model as RCHRES), impervious land areas (IMPLND) and pervious land areas (PERLND). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various land uses in that subwatershed. Water and pollutants from the land segments in a given subwatershed flow into the RCHRES in that subwatershed. Point discharges and withdrawals of water and pollutants are simulated as flowing directly to or withdrawing from a particular RCHRES as well. Water and pollutants from a given RCHRES flow into the next downstream RCHRES. The network of RCHRESs is constructed to mirror the configuration of the stream segments found in the physical world. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed. Due to the complex land uses and tributary networks of the tidal areas, HSPF is well suited for providing runoff inputs to a suitable tidal model, provided that the tidal model possesses the ability to receive temporally and spatially varying inputs from HSPF.

4.1.2 Modeling Areas with Combined Sewers

The City of Richmond modeled the extent of the combined and separate sanitary sewer network for the James River Waste Water Treatment Plant (WWTP) permit requirements (permit number VA0063177). The area draining to each combined sewer overflow (CSO) outfall was modeled with a modified Storm Water Management Model (SWMM). The number of overflows, the flow rate, and bacteria load from each overflow event was modeled annually from January 1999 to the present. This modeling is completed after each year, as the permit requires. SWMM is an accepted tool used to model complex CSO controls and complicated urban stormwater management.

MapTech incorporated the results of the SWMM modeling into a HSPF and CE-QUAL-W2 modeling process in order to separate the inputs from land surfaces versus the inputs from the sanitary sewer. First, HSPF was run in order to estimate the overland runoff volume, bacteria inputs, and the in-stream processes of the riverine segments. HSPF is an accepted tool used to model these processes and is commonly used in TMDL development. Next, the SWMM flow was subtracted from the flow output from HSPF for each CSO contributing subwatersheds (referred to as sewersheds). These values were used as a withdrawal from the sewershed to maintain the proper water mass balance within the model. Then, the flow output from HSPF was subtracted from the SWMM flow for each sewershed to calculate the flow from the sanitary sewer only. Finally, the bacteria load output from HSPF was subtracted from the SWMM bacteria load for each sewershed to calculate the bacteria load from the sanitary sewer only. The sanitary sewer values were then modeled as point sources into the impacted water body (*e.g.,* James River, Gillie Creek, Almond Creek) within the HSPF framework.

For allocation modeling, the SWMM model was run for existing conditions and the final implementation scenario that the City of Richmond has planned in their Phase III CSO

Program Project Plan (Scenario E; Greeley and Hansen, 2006). These were again incorporated into the HSPF and CE-QUAL-W2 models to simulate the scenarios along with land-based bacteria reductions.

4.1.3 Modeling Tidal Impairments

CE-QUAL-W2 (Army Corps of Engineers, 2003) meets the requirements of modeling the tidal portion of this system, including time varying point and non-point sources, wind, tides, a first order decay-based general quality constituent component (including a settling routine for fecal coliform if desired) and continuous simulation. The model's main limitation is its lateral averaging, which is why it is preferred for use with narrow bodies of water. An explanation of why this model is a good choice for a river system such as the James River (tidal) section is referenced in "Tidal Estuary Model Recommendation for use in the Chowan and Tennessee River TMDL" (MapTech, 2004).

The CSO contributions were setup as explained previously and used as input to the CE-QUAL-W2 model of the James River (tidal) impairment segment. HSPF was used to model the tributaries to this segment and the results were formatted for use as inputs to the CE-QUAL-W2 model also.

4.2 Model Setup

Hourly precipitation data was available within the watershed at the Richmond/Byrd Airport NCDC Coop station #447201. Missing values (four hourly values within 1948 to 1955) were filled using daily precipitation from the Petersburg NCDC Coop station #446656.

4.2.1 Subwatersheds

To adequately represent the spatial variation in the watershed, the James River – City of Richmond drainage area was divided into sixty-seven (67) subwatersheds (Figures 4.1 and 4.2, Table 4.1) for the purpose of modeling hydrology. The rationale for choosing these subwatersheds was based on the availability of water quality data, the limitations of the HSPF model, and the sewersheds previously modeled using SWMM. The HSPF model is constrained by the number of operations that it is capable of representing and, thus, necessitated a division of the watershed model into two distinct, linked HSPF models. The output from one model was then routed into the next downstream model. This division occurred between subwatersheds 9 and 10 where the river changes from riverine to tidally influenced.

Figure 4.1 shows all subwatersheds, which were used to achieve the unified model. Figure 4.2 shows the Richmond subwatersheds/sewersheds, which are numbered 42 through 79. Table 4.1 notes the subwatersheds containing the impaired stream segments and all contributing subwatersheds for each impairment. The CSO number corresponding to each sewershed can be found by subtracting 40 from the sewershed number (*e.g.*, subwatershed #79 is the area draining to CSO #39).

The upstream James River flow and water quality was an input to subwatershed 1. Water quality data (i.e., fecal coliform concentrations) are available at specific locations throughout the watershed. Subwatershed outlets were chosen to coincide with monitoring stations, when appropriate, since output from the model can only be obtained at the modeled subwatershed outlets.

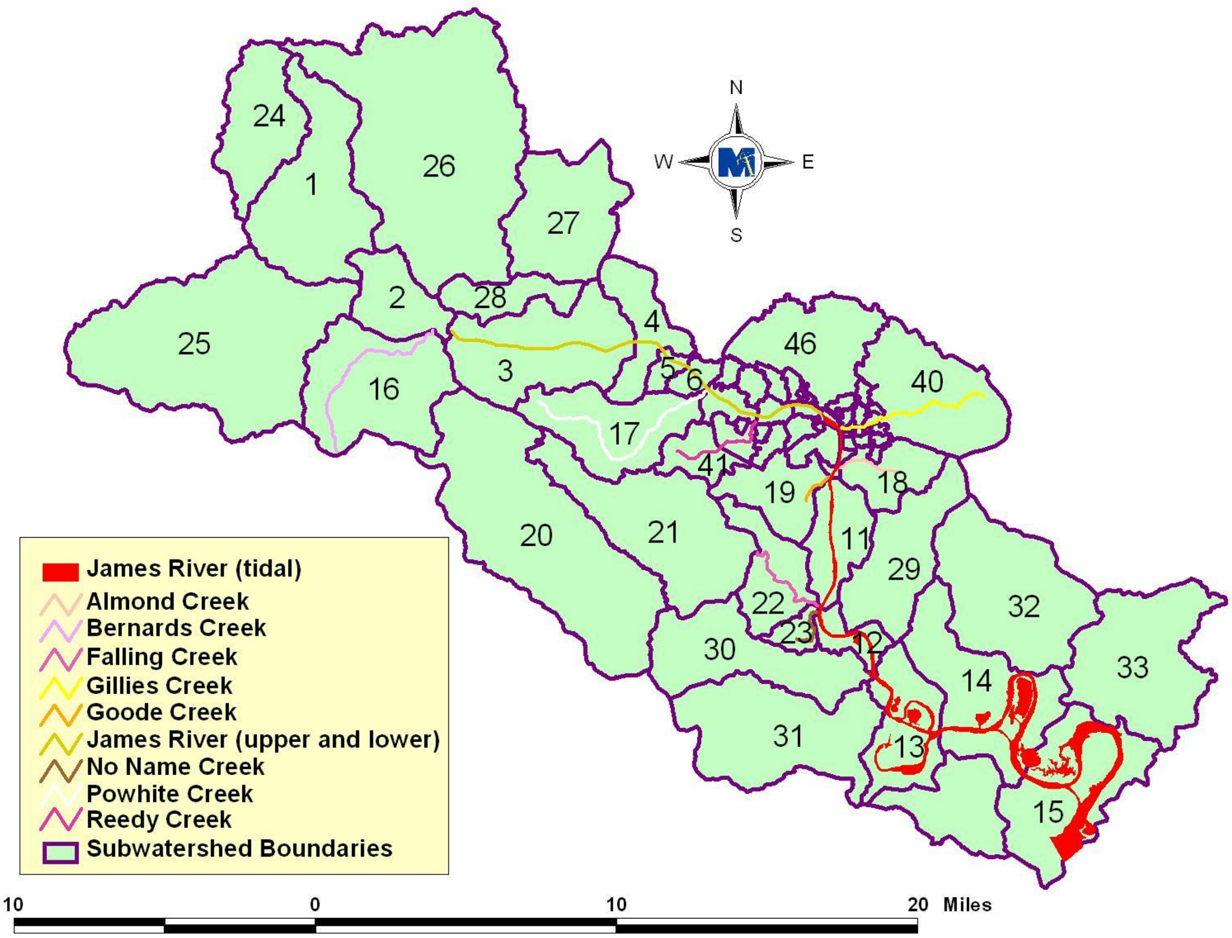

Figure 4.1 All subwatersheds delineated for modeling in the James River – City of Richmond study area.

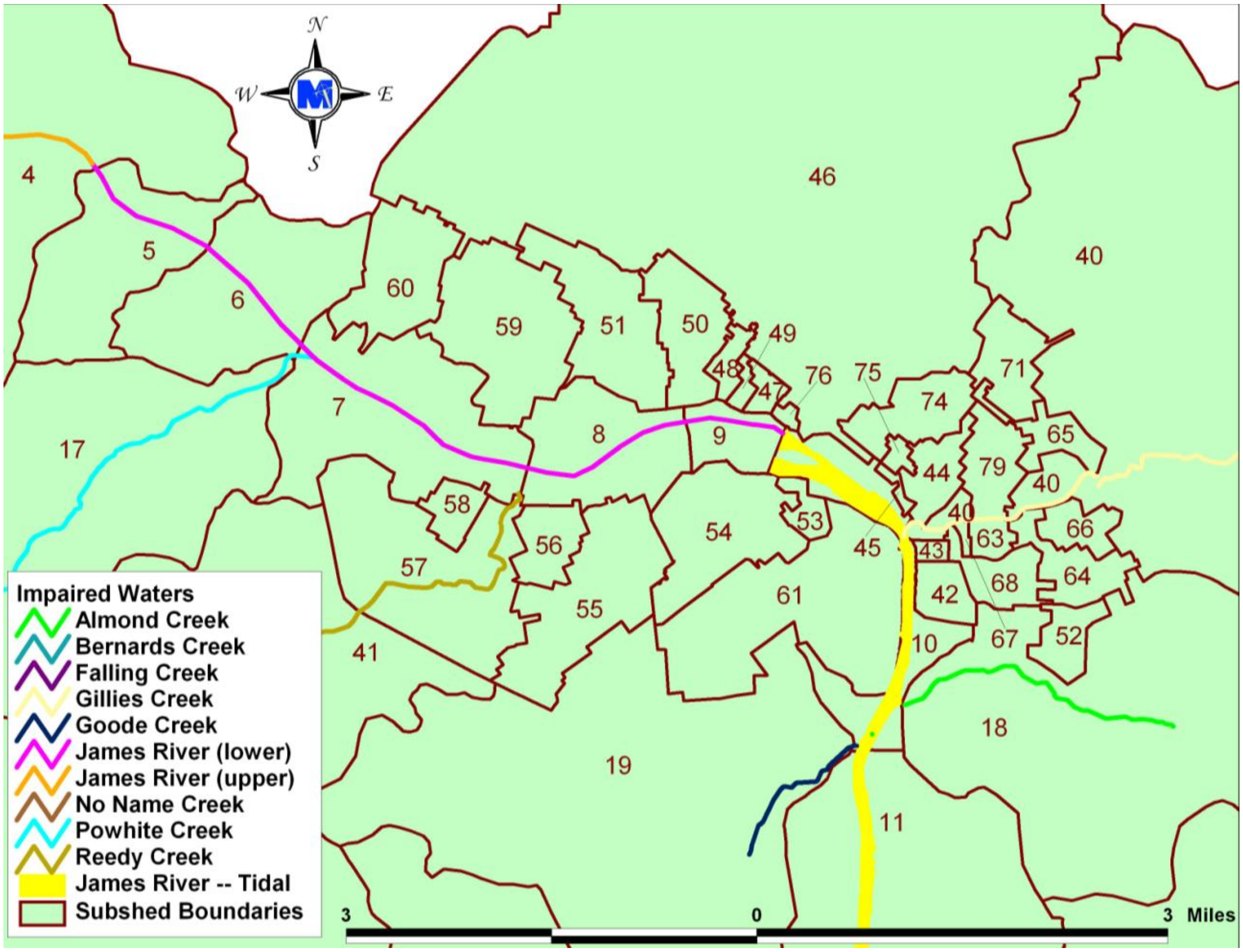

Figure 4.2 Richmond subwatersheds delineated for modeling in the James River – City of Richmond area.

Table 4.1 Impairments and subwatersheds within the James River – City of Richmond study area.

Impairment	Impaired Subwatershed(s)	Outlet	Contributing Subwatersheds
Almond Creek	18	18	18, 52
Bernards Creek	16	16	16
Falling Creek	22	22	20, 21, 22
Gillie Creek	40	40	40, 44, 63-68, 71, 79
Goode Creek	19	19	19
James River (lower)	half of 7, 8, 9	9	1-9, 16, 17, 24-28, 41, 47-51, 55-60, 76
James River (tidal)	10-15	15	1-79 (All)
No Name Creek	23	23	23
Powhite Creek	17	17	17
Reedy Creek	41, 57	57	41, 57

In an effort to standardize modeling efforts across the state, VADEQ has required that fecal bacteria models be run at a 1-hour time-step. The HSPF model requires that the time of concentration in any subwatershed be greater than the time-step being used for the model. These modeling constraints as well as the desire to maintain a spatial distribution of watershed characteristics and associated parameters were considered in the delineation of subwatersheds. The spatial division of the watersheds allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watersheds.

4.2.2 Land Uses

The MRLC land use grid identified 14 land use types in the watersheds. The 14 land use types were consolidated into categories based on similarities in hydrologic and waste application/production features (Table 4.2). Within each subwatershed, up to the ten land use types were represented. Each land use in each subwatershed has hydrologic parameters (*e.g.,* average slope length) and pollutant behavior parameters (*e.g.,* fecal coliform accumulation rate) associated with it. Table 4.2 shows the consolidated land use types in the study area. These land use types are represented in HSPF as pervious land segments (PERLNDs) and impervious land segments (IMPLNDs). Impervious areas in the watershed are represented in four IMPLND types, while there are ten PERLND types, each with parameters describing a particular land use. Some IMPLND and PERLND parameters (*e.g.,* slope length) vary with the particular subwatershed in which they are located. Others vary with the season (*e.g.,* upper zone storage) to account for plant growth, die-off, and removal.

Figure 4.3 shows the land uses used in modeling the James River – City of Richmond study area. Table 4.3 shows the breakdown of land uses within the drainage area of each impairment. These acreages represent only what is within the boundaries of the James River – City of Richmond study area; these values do not include the James River drainage upstream of subwatershed 1. Barren was combined with forest in Figure 4.3.

Table 4.2 Consolidation of MRLC 2001 land use categories for the James River – City of Richmond drainage area used in HSPF modeling.

TMDL Land use Categories	Pervious/Impervious (Percentage)	MRLC Land use Classifications (Class Number)
Water	Pervious (100%)	Open Water (11)
Open Space	Pervious (80%) Impervious (20%)	Developed Open Space (21)
LMIR	Pervious (70%) Impervious (30%)	Low Intensity Residential (22) Medium Intensity Residential (23)
Commercial	Pervious (60%) Impervious (40%)	Commercial/Industrial/Transportation (24)
Barren	Pervious (90%) Impervious (10%)	Barren Land (31)
Forest	Pervious (100%)	Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)
Pasture Hay	Pervious (100%)	Pasture/Hay (81)
Crop	Pervious (100%)	Row Crops (82)
Wetlands	Pervious (100%)	Woody Wetlands (90) Emergent Herbaceous Wetlands (95)
Livestock Access (LAX)	Pervious (100%)	Pasture/Hay (81) near streams

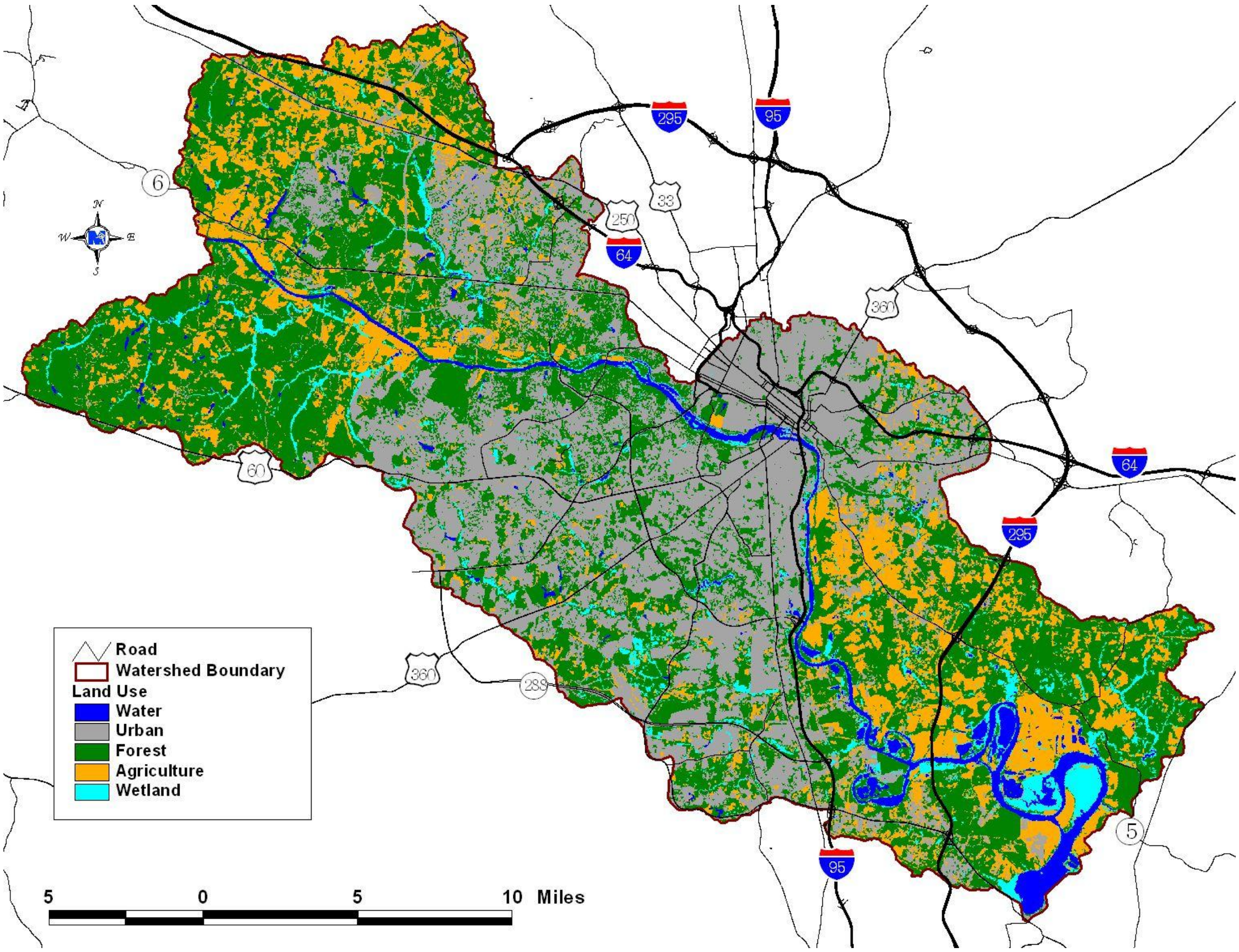

Figure 4.3 Land uses (2001) in the James River – City of Richmond area watershed.

Table 4.3 Spatial distribution of land use acreages in the James River – City of Richmond study area (2001).

Impaired Segment	Barren	Commercial	Crop	Forest	LAX	LMIR	Open Space	Pasture/Hay	Water	Wetland	Total acres
Almond Creek	56	61	150	807	0	796	689	688	23	72	**3,342**
Bernards Creek	0	8	239	6,605	29	342	2,077	975	41	616	**10,932**
Falling Creek	55	633	323	12,099	15	8,204	15,192	1,164	295	963	**38,943**
Gillie Creek	96	424	257	2,597	2	3,744	3,226	721	21	146	**11,233**
Goode Creek	15	399	0	541	0	1,913	1,253	0	3	13	**4,137**
James River (lower)	733	2,467	3,661	64,514	529	27,298	10,748	19,144	3,817	4,199	**137,110**
James River (tidal)	1,923	4,973	11,451	119,905	677	49,678	40,455	37,214	11,250	11,944	**289,470**
No Name Creek	3	101	34	263	0	348	297	28	1	25	**1,100**
Powhite Creek	42	84	23	2,267	1	1,536	3,146	108	0	180	**7,387**
Reedy Creek	10	248	0	614	0	1,202	1,014	0	0	20	**3,108**
Total Study Area	**1,923**	**4,973**	**11,451**	**119,905**	**677**	**49,678**	**40,455**	**37,214**	**11,250**	**11,944**	**289,470**

Die-off of fecal coliform can be handled implicitly or explicitly. For land-applied fecal matter (mechanically applied and deposited directly), die-off was addressed implicitly through monitoring and modeling. Samples of collected waste prior to land application (*i.e.*, dairy waste from loafing areas) were collected and analyzed by MapTech. Therefore, die-off is implicitly accounted for through the sample analysis. Die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal coliform entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

4.3 Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.*, stream geometry and resistance to flow). This data are entered into HSPF via the Hydraulic Function Tables (F-tables). The F-tables developed consist of four columns: depth (ft), area (ac), volume (ac-ft), and discharge (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. The area listed is the surface area of the flow in acres. The volume corresponds to the total volume in the reach, and is reported in acre-feet. The discharge is simply the stream outflow, in cubic feet per second.

In order to develop the entries for the F-tables, a combination of the NRCS Regional Hydraulic Geometry Curves (NRCS, 2006), Digital Elevation Models (DEM), nautical charts, and bathymetry data was used. The nautical charts and bathymetry data includes the elevation of stream and rivers below mean sea level (negative elevations). The NRCS has developed empirical formulas for estimating stream top width, cross-sectional area, average depth, and flow rate, at bank-full depth as functions of the drainage area for regions of the United States. Appropriate equations were selected based on the geographic location of the James River – City of Richmond watershed. The NRCS equations developed from data in the rural piedmont plateau of North Carolina were implemented for the non-Richmond and non-tidal subwatersheds. Using these NRCS equations, an entry was developed in the F-table that represented a bank-full situation for the streams at each non-tidal subwatershed outlet. A profile perpendicular to the channel was generated showing the stream profile height with distance for each subwatershed outlet (Figure 4.4). Consecutive entries to the F-table are generated by estimating the volume of water and surface area in the reach at incremental depths taken from the profile.

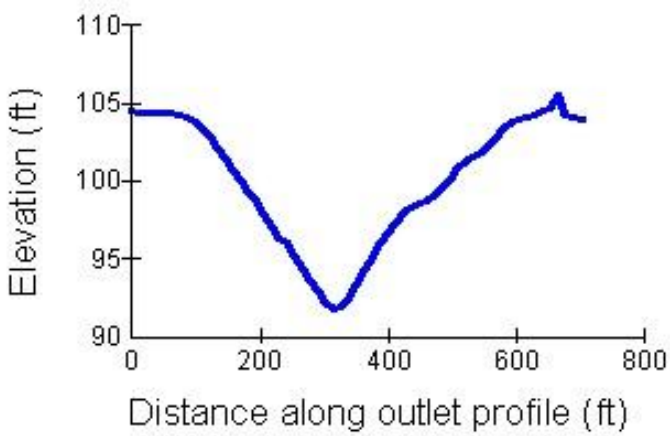

Figure 4.4 Stream profile representation in HSPF.

Greeley and Hansen previously modeled the subwatersheds influenced by the stormwater and sewer collection within Richmond City using a modified SWMM. HSPF was used to model the overland runoff, interflow, and groundwater contributions from these subwatersheds (42-79). The output of SWMM, in combination with HSPF, was used to determine the amount of overland flow treated by the sewer system, the total CSO flow volume and bacteria load, and the relative bacteria contribution from sewage and wash-off.

The tidally influenced subwatersheds (10-15) were modeled using CEQUAL-W2 and did not require calculated F-tables in HSPF (Section 4.1.3). Placeholder F-tables were used for these areas to run the model.

Conveyance was used to facilitate the calculation of discharge in the reach with values for resistance to flow (Manning’s *n*) assigned based on recommendations by Brater and King (1976) and shown in Table 4.4. The conveyance was calculated for each of the two floodplains and the main channel; these figures were then added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). Average reach slope and reach length were obtained from GIS layers of the watershed, which included elevation from DEMs and a stream-flow network based on National Hydrography Dataset (NHD) data. The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (in ft^3/s) at a given depth. An example of an F-table used in HSPF is shown in Table 4.5.

Table 4.4 Summary of Manning's roughness coefficients for channel cells*.

Section	Upstream Area (ha)	Manning's *n*
Intermittent stream	18 - 360	0.06
Perennial stream	360 and greater	0.05

*Brater and King (1976)

Table 4.5 Example of an F-table calculated for the HSPF model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (ft^3/s)
0	0	0	0
3.28	0.71	1.41	17.07
6.56	1.89	5.15	45.23
9.84	2.54	12.18	85.02
13.12	4.77	24.80	152.82
16.40	56.55	77.51	637.72
19.68	1,047.22	1,635.10	18,846.85
22.96	2,875.31	7,405.99	69,827.77
26.24	3,495.32	18,464.40	133,806.76
29.52	4,426.89	31,720.10	160,393.97

4.4 Selection of a TMDL Critical Condition

EPA regulations at 40 CFR 130.7 (c)(1) require that TMDLs take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the James River – City of Richmond study area is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken in order to meet water quality standards. Fecal bacteria sources within the James River – City of Richmond study area are attributed to both point and non-point sources. Critical conditions for waters impacted by land-based non-point sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context also, include non-point sources that are not precipitation driven (*e.g.*, fecal deposition to stream). The nature of the CSOs alter the critical conditions by contributing high bacteria loads of mixed sewage and stormwater runoff during high precipitation events, but during dry weather much of the stream flow is routed to the treatment plant and treated along with the daily sewage inputs. The CSOs, therefore, have an affect of skewing the critical conditions toward wet-weather flow conditions. The City of Richmond's on-going implementation of the CSO Long Term Control Plan (LTCP) reduces overflow frequency and provides primary treatment during both dry and wet-weather flows. Future implementation of the LTCP will provide additional treatment and overflow reductions.

A description of the data used in these analyses is shown in Table 2.1 in Chapter 2. Graphical analyses of fecal coliform concentrations and flow duration intervals showed that there were different critical flow levels for different segments of the James River. The data from the tributaries to the James River also showed different critical periods. Data at the VADEQ monitoring station 2-FAC000.85 at Falling Creek shown in Figure 4.5 is an example of a stream with fecal coliform standard (400 cfu/100mL) violations during all flow regimes. This demonstrates that this stream should have all flow regimes represented in the allocation modeling time period. All other graphs are shown in Appendix B.

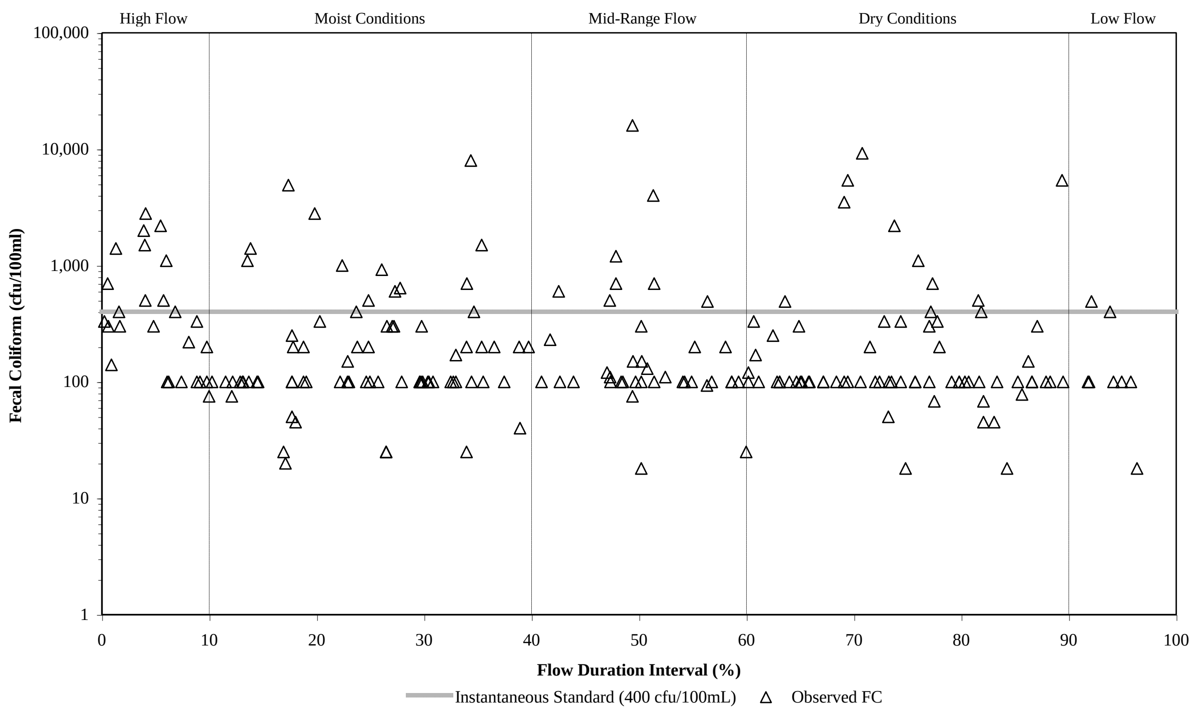

Figure 4.5 Fecal coliform concentrations at 2-FAC000.85 in Falling Creek versus discharge at USGS Gaging Station #02037500.

The data from the stations in the James River show fewer violations at low flow, which can indicate that even when the flow in the James River is low, there is enough water to dilute contributions from point sources and directly deposited sources (Figures B.11 through B.45). It is reasonable to assume that this may be because the James River Waste Water Treatment Plant treats the stream flow from tributaries during dry flow conditions due to the combined sewer system in Richmond. Although the low flow levels are not as critical as the other regimes, the allocation model of the James River should use representative rainfall and flow data relating to all recorded historical data.

The data from Almond Creek, Falling Creek (at 2-FAC000.85), Gillie Creek (at 2-GIL000.03 and 2-GIL000.42), Goode Creek, Powhite Creek, and Reedy Creek show that there are violations during all flow regimes (Figures B.1, 2.1, B.6, B.7, B.9, B.52, B.53, and B.54). The allocation model of these streams should use representative rainfall and flow data relating to all recorded historical data.

The data from Bernards Creek showed no violations during the low flow regime (Figure B.2). Although the low flow levels are not as critical as the other regimes, the allocation model of Bernards Creek should use representative rainfall and flow data relating to all recorded historical data based on data in the surrounding areas. During implementation planning, it may be necessary to target the high flow conditions.

Based on this analysis, a time period for calibration and validation of the model was chosen based on the overall distribution of wet and dry seasons (Section 4.5) in order to capture a wide range of hydrologic circumstances for all impaired streams in this study area. The resulting periods for calibration, validation, and allocation for each impaired stream are presented in Section 4.5.

4.5 Selection of Representative Modeling Periods

As discussed more in Section 4.8.1, the hydrology of this area was calibrated in a separate project (Total Maximum Daily Load Development for the James River and Tributaries – Lower Piedmont Region, VADEQ 2007a). Hydrology validation was preformed to verify the HSPF model's response during the time period chosen for water quality modeling of the James River – City of Richmond area. Selection of a hydrology validation modeling period was based on two factors: availability of data (discharge, water-quality, and previous CSO modeling) and the need to represent critical hydrological conditions. The upgrades to the CSO collection and treatment system were accounted for when the modeling was simjulated at existing conditions. Modeled CSO output was available during this time period.

Water quality modeling was preformed during this time period. The period 10/1/1999 to 9/30/2003 was chosen as the calibration period. This period contained 396 water quality data points spread over 20 VADEQ stations. The period from 10/1/2003 to 12/30/2006 was chosen as the validation period, with 91 data points over 7 VADEQ stations.

The critical flow regime study (Section 4.4) showed that all flow regimes, but most critically high flows, should be represented in the modeling time periods of the impaired streams in this study. The hydrology validation/water quality calibration and validation time period, 10/1/1999 to 9/30/2003, has both the highest and lowest daily average streamflow and precipitation, which represent the high and low flow critical regimes (Figures 4.6 and 4.7).

The figures are shown here to demonstrate the historical annual and seasonal stream flow and precipitation and how the selected time period encompasses a representative range of values.

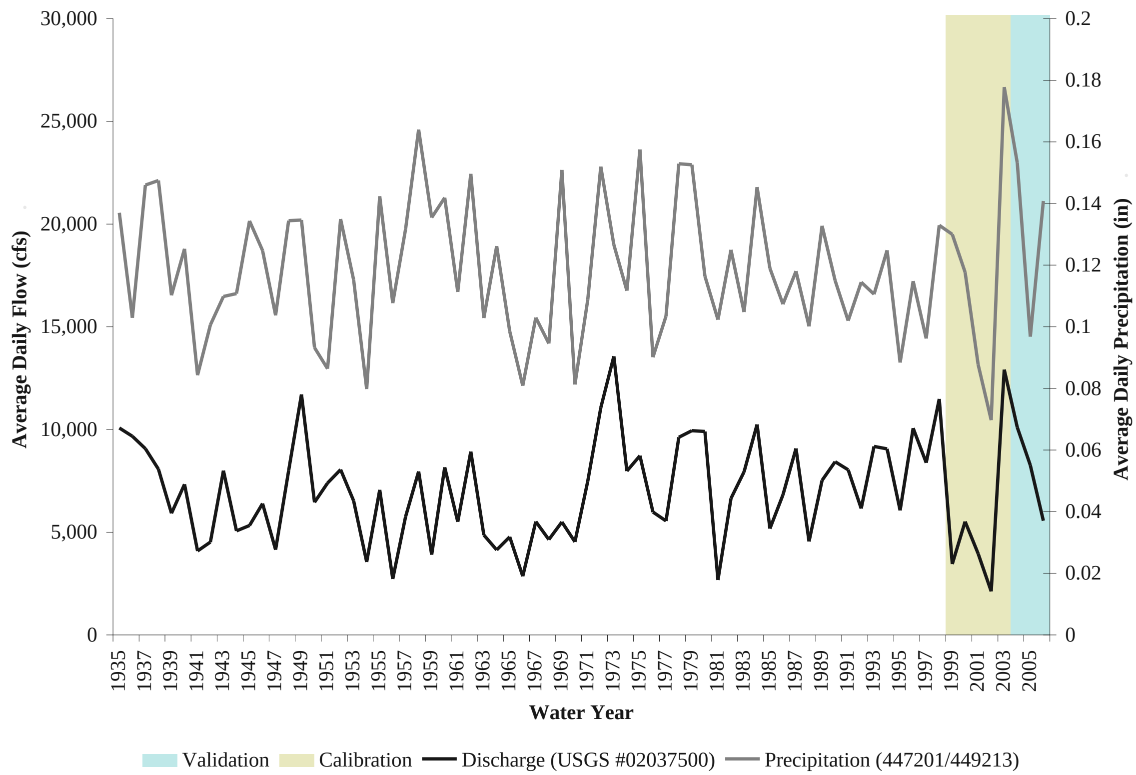

Figure 4.6 Water quality modeling time periods, annual historical flow (USGS Station 02037500), and precipitation (Station 447201/449213) data.

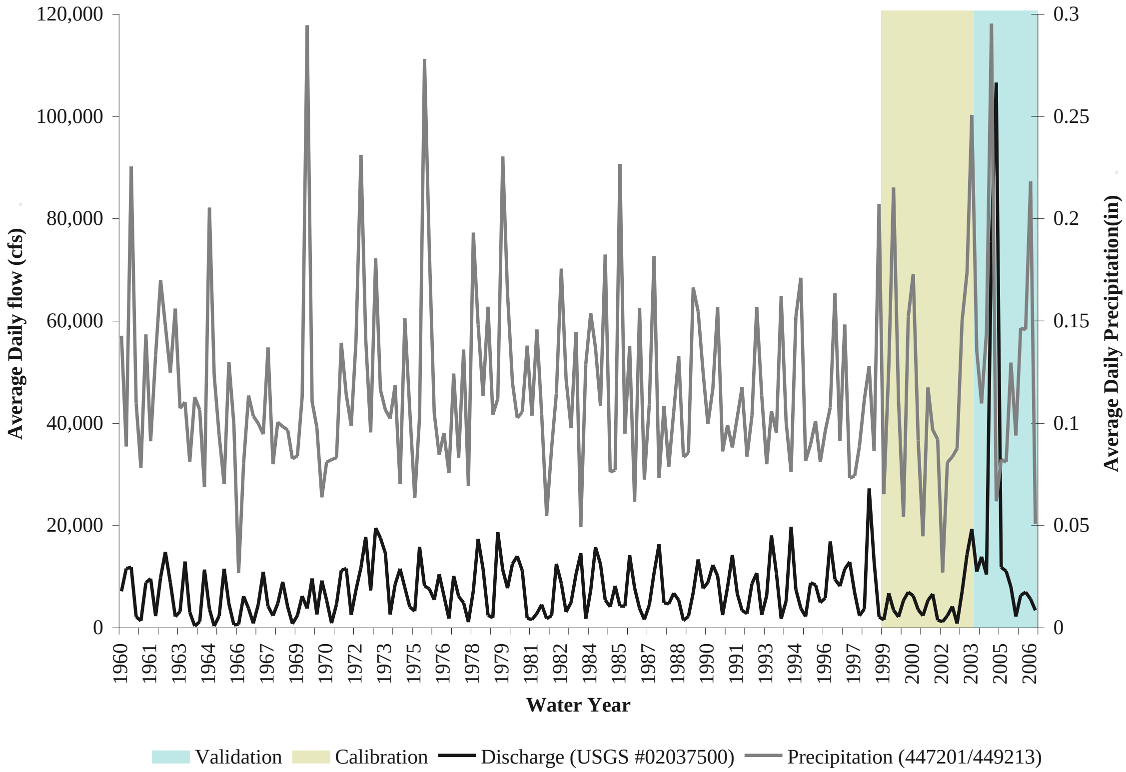

Figure 4.7 Water quality modeling time periods, seasonal historical flow (USGS Station 02037500), and precipitation (Station 447201/449213) data.

The City of Richmond has selected 1974-1978 as the allocation modeling time period and has modeled various implementation scenarios using this rainfall record. Based on a statistical analysis conducted during this study, this is a reasonable choice for representative rainfall.

4.6 Source Representation

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (*e.g.*, animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Direct depositions by wildlife were modeled as being deposited from 6:00 AM to 6:00 PM. Once in stream, die-off is represented by a first-order exponential equation.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.*, population). Depending on the timeframe of the simulation being run, different numbers were used. Data representing 2002 were used for the water quality calibration period (1999-2003) and data representing 2006 were used for validation period (2003-2006). Data representing 2006 were used for the allocation runs in order to represent current conditions.

4.6.1 Permitted Sources

Thirty-three (33) point sources are permitted to discharge water into surface waters in the James River – City of Richmond study area through the Virginia Pollutant Discharge Elimination System (VPDES) (Table 3.2). Section 3.2 discusses these permits in more detail. Twelve (12) of these VPDES permits are permitted for fecal bacteria control. For calibration and validation condition runs, recorded flow and fecal coliform concentration or Total Residual Chlorine (TRC) levels documented by the VADEQ were used as the input for each permit (Table 4.7). The TRC data was related to fecal colifrom concentrations using a regression analysis. Table 4.6 shows the minimum and maximum discharge rate in million gallons per day (MGD) and the minimum and maximum fecal coliform bacteria concentration in colony forming units per 100 milliliters (cfu/100mL). These values are the sums of all the data for each outfall.

The design flow capacity was used for allocation runs. This flow rate was combined with a fecal coliform concentration of 200 cfu per 100 ml to ensure that compliance with state water quality standards could be met even if permitted loads were at maximum levels. The design flow rates and fecal coliform bacteria concentrations are shown in Table 4.6. Table 4.7

shows the permits discharging only water to the streams. This table also shows values used for calibration, validation and allocation (design flows).

Nonpoint sources of pollution that were not driven by runoff (*e.g.*, direct deposition of fecal matter to the the stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

Table 4.6 Flow rates and bacteria loads used to model VADEQ active permits in the James River – City of Richmond study area.

		Calibration/Validation				Allocation	
		Flow Rate (MGD)		Bacteria Concentration (cfu/100mL)		Flow Rate (MGD)	Bacteria Concentration (cfu/100mL)
VADEQ Permit Number	Facility Name	Min	Max	Min	Max	Design Flow	Fecal Coliform Geometric Mean Standard
VA0003077	DuPont Teijin Films	0.027	0.70	0.083	527.6	1.38	200
VA0024163	Mary Mother of the Church Abbey WWTP	0.001	0.01	200.0	200.0	0.015	200
VA0024996	Falling Creek WWTP	4.90	13.6	0.0	10.3	10.1	200
VA0026557	Phillip Morris	1.26	2.50	ND*	ND*	2.9	200
VA0027910	Manakin Farms Inc	0.0	0.11	0.0	8.18	0.07	200
VA0028622	Harbour East Village WWTP	0.030	0.48	3.47	24.9	0.09	200
VA0060194	Proctors Creek WWTP	8.596	10.987	4.1	16.2	27	200
VA0063177	Richmond WWTP - Outfall 001	25.4	77.0	0.0	5.50	75.0	200
VA0063649	Richmond Country Club WWTP	0.0	0.011	1.67	8.54	0.0036	200
VA0063690	Henrico County WWTP	25.7	69.3	1.0	9.0	75.0	200
VA0066494	Youngs Mobile Home Park	0.001	0.003	4.28	33.01	0.015	200
VA0090727	Dutoy Creek WWTP	0.0026	0.04	1.0	7.00	0.25	200

*ND=Not Determined

Table 4.7 Flow rates used to model VADEQ active permits in the James River – City of Richmond study area.

VADEQ Permit No.	Facility Name	Flow Rate (MGD) Min	Flow Rate (MGD) Max	Design Flow (MGD)
VA0002780	The Sustainability Park LLC [1]	0.51	1.19	2.1
VA0004146	Dominion Chesterfield Power Station [2]	ND [3]	ND	1,085
VA0088153	Trans Industrial Incorporated	ND	ND	ND
VA0004880	Du Pont De Nemours E I and Co Inc James River Pl	1.06	4.31	3.83
VA0004669	E I du Pont de Nemours and Co - Outfall 001	13.4	55.5	56.9
VA0005312	Honeywell Resins and Chemicals, LLC - Chesterfield	5.43	39.34	39.34
VA0005720	Motiva Enterprises LLC - Richmond Terminal-Texaco	0.0001	0.187	0.008
VA0029165	Kinder Morgan Operating LP - Bickerstaff Road	0.0	0.043	0.043
VA0054291	IMTT - Virginia East	0.004	0.005	0.010
VA0054330	Hammaker East	0.0005	0.0005	0.0005
VA0055409	IMTT – Virginia West	0.0005	0.0005	0.005
VA0058378	Kinder Morgan Southeast Terminals LLC - Richmond 2	0.0	0.33	0.438
VA0084565	Powhatan Courthouse Water Treatment Plant	0.007	0.007	0.007
VA0085499	Spruance Genco LLC	0.59	4.02	2.34
VA0086151	Kinder Morgan Operating LP – Deepwater Terminal	0.0	0.56	0.53
VA0087734	VEPCO Maintenance and Supply Center	0.013	9.96	3.88
VA0090964	Rehrig International Incorporated	0.088	3.13	3.16
VA0091154	Camp Holly Springs	0.007	0.007	0.007
VA0091197	Henrico County Water Treatment Plant	0.70	0.70	0.70
VA0091499	BFI Old Dominion Landfill	0.43	2.34	4.47
VA0091642	Defense Supply Center Richmond	0.80	1.82	15.0

[1] Facility currently operating at Tier 1 – industrial discharge, which is not believed to contribute bacteria. Upon the issuance of a Certificate To Operate (CTO) for Tiers 2 & 3, a municipal discharge of 3.0 MGD will apply.
[2] When combined with their withdrawals this discharger had zero net impact on stream flows.
[3] ND = Not Determined

4.6.2 Private Residential Sewage Treatment

The number of septic systems in the James River – City of Richmond study area was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the subwatersheds. During allocation runs, the number of households was projected to 2006, based on current growth rates (USCB, 2000) resulting in 26,670 septic systems and 217 uncontroled discharges (Table 4.8).

Table 4.8 Estimated failing septic systems and straight pipes for 2006 in the James River – City of Richmond study area.

Impaired Segment	Septic Systems	Failing Septic Systems	Uncontrolled Discharges
Almond Creek	296	35	2
Bernards Creek	1,201	43	3
Falling Creek	5,705	152	7
Gillie Creek	556	80	21
Goode Creek	74	4	2
James River (lower)	10,339	871	124
James River (tidal)	26,670	1,619	217
No Name Creek	101	6	1
Powhite Creek	1,288	44	4
Reedy Creek	118	5	4

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. In accordance with estimates from Raymond B. Reneau, Jr. from Virginia Tech, a 40% failure rate for systems designed and installed prior to 1964, a 20% failure rate for systems designed and installed between 1964 and 1984, and a 5% failure rate on all systems designed and installed after 1984 was used in development of the TMDLs for the James River – City of Richmond area. Total septic systems in each category were calculated using U.S. Census Bureau block demographics. The applicable failure rate was multiplied by each total and summed to get the total failing septic systems per subwatershed. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors to account for more frequent failures during wet months.

Uncontrolled discharges (straight pipes) were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category "other means" were assumed to be disposing sewage via uncontrolled discharges. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. These values were then adjusted based on correspondence with the Virginia Department of Health (VDH) for Goochland, Powhatan, Chesterfield, and Henrico County offices. Fecal coliform loads for each discharge were calculated based on the fecal density of human waste and the wasteload for the average size household in the subwatershed. The loadings from uncontrolled discharges were applied directly to the stream in the same manner that point sources are handled in the model.

During the model calibration/validation period, (October 1999 to December 2006) there were 22 total reported sewer overflows. It was assumed that additional occurrences of sewer overflows were likely undetected; therefore a statistical analysis of meteorological events and sewer overflows was determined and a projection of undetected sewer overflows was performed. This analysis involved using the daily total precipitation and the 3-day prior rainfall for each day an overflow was reported. The sewer overflow event reports contained an estimate of the volume of sewage discharged, so the model includes these discharges. The concentration of fecal bacteria discharged was considered equivalent to the concentration of septic tank effluent, and the magnitude of the discharge was estimated as the average discharge volume of reported sewer overflow events per subwatershed. As some biodegradation occurs in a septic system, it is felt that the estimate of concentration is conservative. The following subwatersheds have sewer overflows and the projected undetected sewer overflows in the model: 3, 6, 13, 14, 16, 18, 19, 22, 23, and 25. These subwatersheds include the James River upper, lower and tidal impairments, Bernards Creek, Almond Creek, Goode Creek, Falling Creek, No Name Creek, and a James River tributary.

4.6.3 Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The amount of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock numbers determined for 2002 were used for the calibration and validation runs, while these numbers were projected to 2006 for the allocation runs. The numbers are based on data provided by Virginia Agricultural Statistics (VASS), with values updated and discussed by VCE, VADCR, NRCS, SWCDs, and FSA as well as taking into account growth rates in these counties as determined from data reported by the Virginia Agricultural Statistics Service (VASS, 1995; VASS, 2002). For land-applied waste, the fecal coliform density measured from stored waste was used, while the density in as-excreted manure was used to calculate the load for deposition on land and to streams (Table 3.14). The use of fecal coliform densities measured in stored manure accounts for any die-off that occurs in storage. The modeling of fecal coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

4.6.3.1 Land Application of Collected Manure

Collection of livestock manure was assumed the case on all dairy farms. The average daily waste production per month was calculated using the number of animal units, weight of animal, and waste production rate as reported in Section 3.3.4. For dairy cows, the only waste assumed to be collected was from currently milking cows and calves. Second, the total amount of waste produced in confinement was calculated based on the proportion of time spent in confinement. Finally, values for the percentage of loafing lot waste collected, based on data provided by SWCD representatives and local stakeholders, were used to calculate the amount of waste available to be spread on pasture and cropland (Table 3.14). Stored waste was spread on pasture and cropland. It was assumed that 100% of land-applied waste is available for transport in surface runoff.

4.6.3.2 Deposition on Land

For cattle, the amount of waste deposited on land per day was a proportion of the total waste produced per day. The proportion was calculated based on the study entitled "Modeling Cattle Stream Access" conducted by the Biological Systems Engineering Department at Virginia Tech and MapTech, Inc. for VADCR. The proportion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

Proportion = [(24 hr) – (time in confinement) – (time in stream access areas)]/(24 hr)

All other livestock (horse, sheep, hogs) were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture land use was area-weighted.

4.6.3.3 Direct Deposition to Streams

The amount of waste deposited in streams each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in "stream access" areas was calculated based on the "Modeling Cattle Stream Access" study. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

For the waste produced on the "stream access" land use, 30% of the waste was modeled as being directly deposited in the stream and 70% remained on the land segment adjacent to the stream. The 70% remaining was treated as manure deposited on land. However, applying it in a separate land-use area (stream access) allows the model to consider the proximity of the deposition to the stream. The 30% that was directly deposited to the stream was modeled in the same way that point sources are handled in the model.

4.6.4 Biosolids

Investigation of VDH data indicated that biosolids applications have occurred within the James River – City of Richmond area. Class B biosolids are permitted to contain up to 1,995,262 cfu/g-dry, as compared with approximately 240 cfu/g-dry for dairy waste. Detailed records of biosolids application location, timing and quantity were available, enabling the water quality modeling to be carried out in an "as applied" fashion, wherein the water quality model received land based inputs of biosolids loads on the day in which they actually occurred. During both model runs, biosolids were modeled as having a fecal concentration of 157,835 cfu/g, the mean value of measured biosolids concentrations observed in several years of samples supplied by VDH for sources applied during 2001 to 2005. Applications were modeled as being spread onto the land surface over a six hour period on the date of reported application, in the case of a multiple day application, loads were split evenly over the period reported. An assumption of proper application was made, wherein no biosolids were modeled as being spread in stream corridors.

4.6.5 Wildlife

For each species of wildlife, a GIS habitat layer was developed based on the habitat descriptions that were obtained (Section 3.3.5). An example of one of these layers is shown in Figure 4.8. This layer was overlaid with the land use layer and the resulting area was calculated for each land use in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the wasteload, fecal coliform densities, and number of animals for each species.

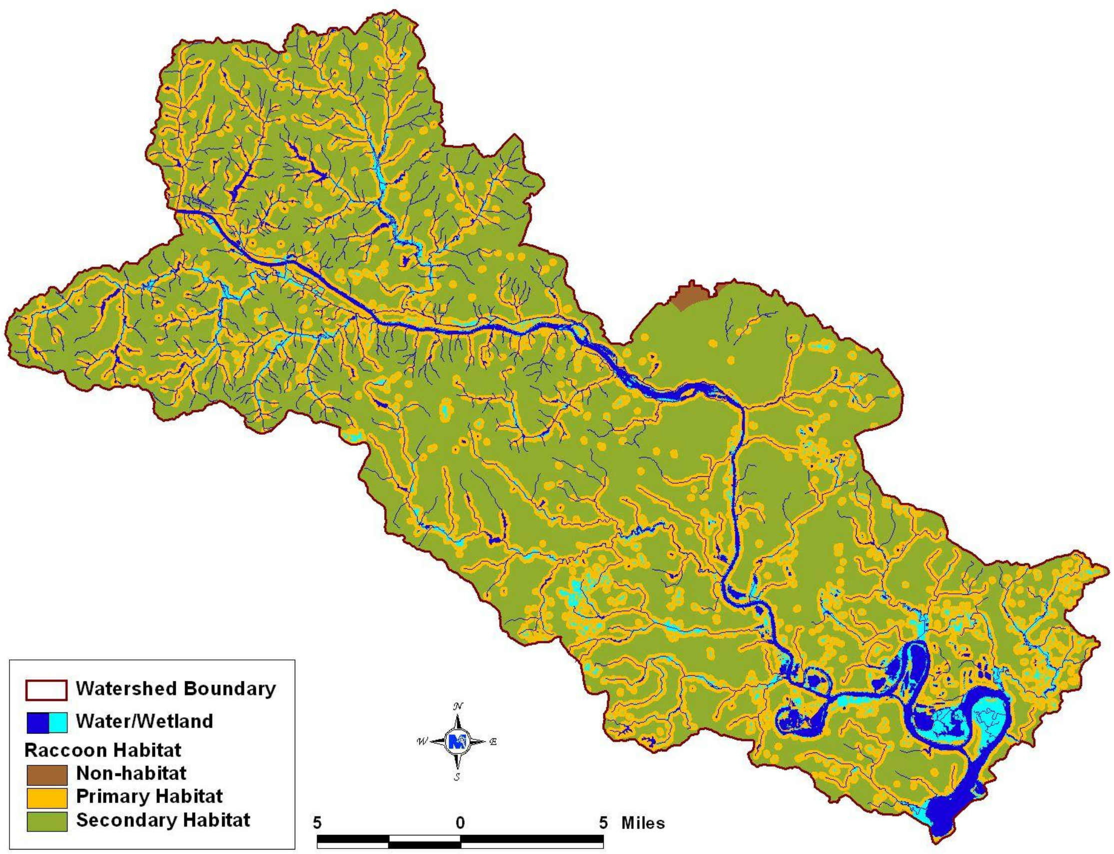

Figure 4.8 Example of raccoon habitat layer in the James River – Richmond area, as developed by MapTech.

For each species, a portion of the total wasteload was considered land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.20). It was estimated that, for all animals other than beaver, 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams. No long-term (1999–2006) adjustments were made to wildlife populations, as there was no available data to support such adjustments.

4.6.6 Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals per house), wasteload, and fecal coliform density are reported in Section 3.3.3. Waste from pets was distributed on residential land uses. The number of households per subwatershed was taken from the 2000 Census (USCB, 1990 and USCB, 2000). The number of animals per subwatershed was determined by multiplying the number of households by the pet population density. The amount of fecal coliform deposited daily by pets in each subwatershed was calculated by multiplying the wasteload, fecal coliform density, and number of animals for both cats and dogs. The wasteload was assumed not to vary seasonally. The populations of cats and dogs were projected from 2000 data to 2006.

4.7 Model Calibration and Validation Processes

Calibration and validation are performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, land use, and topographic data. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable. Sensitivity analyses were performed on the HSPF model to show how small changes in certain model parameters affect the output from the model (Appendix D).

4.7.1 HSPF - Hydrologic Calibration and Validation

Hydrologic calibration was conducting during the development of Total Maximum Daily Load Development for the James River and Tributaries – Lower Piedmont Region (VADEQ, 2007a) and Total Maximum Daily Load Development for the Upham Brook watershed (VADEQ, 2007b). The model was calibrated for hydrologic accuracy using daily flow data from USGS Gaging Station 02037500 on the James River for the period October 2000 through September 2003 for the James River and Tributaries – Lower Piedmont Region. The calibration of stream flow in Upham Brook was performed using daily flow data from USGS Gaging Station 02042426 on the Upham Brook for the period October 1991 through September 1994. The results of these calibrations are shown in their respective TMDL technical documents. The changes made to the hydrologic parameters of the rural land uses in the James River and Tributaries – Lower Piedmont Region were the same percent changes made to the hydrologic parameters of the rural land uses in James River – City of Richmond. The same principles were followed when using the changes to the urban land uses from the Upham Brook watershed.

HSPF parameters that were adjusted during the hydrologic calibration represented: the amount of evapotranspiration from the root zone (LZETP), the recession rates for groundwater (AGWRC) and interflow (IRC), the length of overland flow (SLSUR), the amount of soil moisture storage in the upper zone (UZSN) and lower zone (LZSN), the amount of interception storage (CEPSC), the infiltration capacity (INFILT), the amount of soil water contributing to interflow (INTFW), deep groundwater inflow fraction (DEEPER), baseflow PET (BASETP), forest coverage (FOREST), slope of overland flow plane (LSUR), groundwater recession flow (KVARY), maximum and minimum air temperature affecting PET (PETMAX, PETMIN, respectively), infiltration equation exponent (INFEXP), infiltration capacity ratio (INFILD), active groundwater storage PET (AGWETP), Manning's *n* for overland flow plane (NSUR), interception (RETSC), and the weighting factor for hydraulic routing (KS). Table 4.9 contains the possible range for the above parameters along with the initial estimate and final calibrated value. State variables in the PERLND water (PWAT) section of the User's Control Input (UCI) file were adjusted to reflect initial conditions.

The percent change between the initial and final calibrated HSPF parameters for the Group 2 and Group 5 watershed were used as the percent change in base parameters for the James River – City of Richmond model.

Table 4.9 Initial hydrologic parameters estimated for the James River – City of Richmond study area, the changes to these parameters during the Group 2 and Group 5 calibrations, and resulting final values.

Parameter	Units	Possible Range of Parameter Value	Initial Parameter Estimate	Group 2 and Group 5 Percent Change	Final Parameter Value
LZSN	in	2.0 – 15.0	5.744 – 15	-58 – -84%	2.0 – 6.0
INFILT	in/hr	0.001 – 0.50	0.072 – 0.259	-99 – 70%	0.001 – 0.233
LSUR	ft	100 – 700	1 – 700	0%	1 – 700
SLSUR	---	0.001 – 0.30	0.002 – 0.279	0%	0.002 – 0.279
KVARY	1/in	0.0 – 5.0	0	0 – 0.20*	0 – 0.20
AGWRC	1/day	0.85 – 0.999	0.98	1.3 – 1.9%	0.993 – 0.999
PETMAX	deg F	32.0 – 48.0	40	0%	40
PETMIN	deg F	30.0 – 40.0	35	0%	35
INFEXP	---	1.0 – 3.0	2	0%	2
INFILD	---	1.0 – 3.0	2	0%	2
DEEPFR	---	0.0 – 0.50	0.01 – 0.02	1150 – 4900%	0.25 – 0.50
BASETP	---	0.0 – 0.20	0.01 – 0.02	400 – 1350%	0.05 – 0.10
AGWETP	---	0.0 – 0.20	0 – 0.01	0%	0 – 0.01
INTFW	---	1.0 – 10.0	1	0%	1
IRC	1/day	0.30 – 0.85	0.5	-40%	0.3
MON-INTERCEPT	in	0.01 – 0.40	0 – 0.20	-99 – 3900%	0.01 – 0.40
MON-UZSN	in	0.05 – 2.0	0.37 – 1.55	-96 – 202%	0.05 – 2.0
MON-MANNING		0.01 – 0.5	0.01 – 0.37	0%	0.04 – 0.37
MON-LZETP	---	0.1 – 0.9	0 – 0.80	-90 – 8900%	0.01 – 0.9
RETSC	in	0.01 – 0.30	0.10	0%	0.1
KS	---	0.0 – 0.9	0.5	0%	0.5

* Represents an addition, not multiplier

For the purpose of validating the hydrologic model of the James River – City of Richmond study area, the model was simulated from 10/1/1999 to 12/31/2006 the time period of interest in this project. The modeled output from subwatershed 3 was compared against the James River USGS Gaging Station #02035000 data. Table 4.10 shows the percent difference (or error) between observed and modeled data for total in-stream flows, upper 10% flows, and lower 50% flows during model calibration. These values represent a close agreement with the observed data, indicating the model was well calibrated and has been validated during a different time period. Figures 4.9 and 4.10 graphically show these comparisons.

Table 4.10 Hydrology validation criteria and model performance from 10/1/1999 through 12/31/2006 at USGS Gaging Station #02035000 on the James River (subwatershed 3).

Criterion	Observed	Modeled	Error
Total In-stream Flow:	3829.73	3986.36	4.09%
Upper 10% Flow Values:	1459.37	1409.59	-3.41%
Lower 50% Flow Values:	651.52	722.85	10.95%
Winter Flow Volume	1029.08	1056.81	2.69%
Spring Flow Volume	1145.77	1172.91	2.37%
Summer Flow Volume	569.40	638.37	12.11%
Fall Flow Volume	1085.48	1118.27	3.02%
Total Storm Volume	3382.54	3467.97	2.53%
Winter Storm Volume	921.99	932.55	1.14%
Spring Storm Volume	1037.93	1047.75	0.95%
Summer Storm Volume	461.75	514.08	11.33%
Fall Storm Volume	960.87	973.59	1.32%

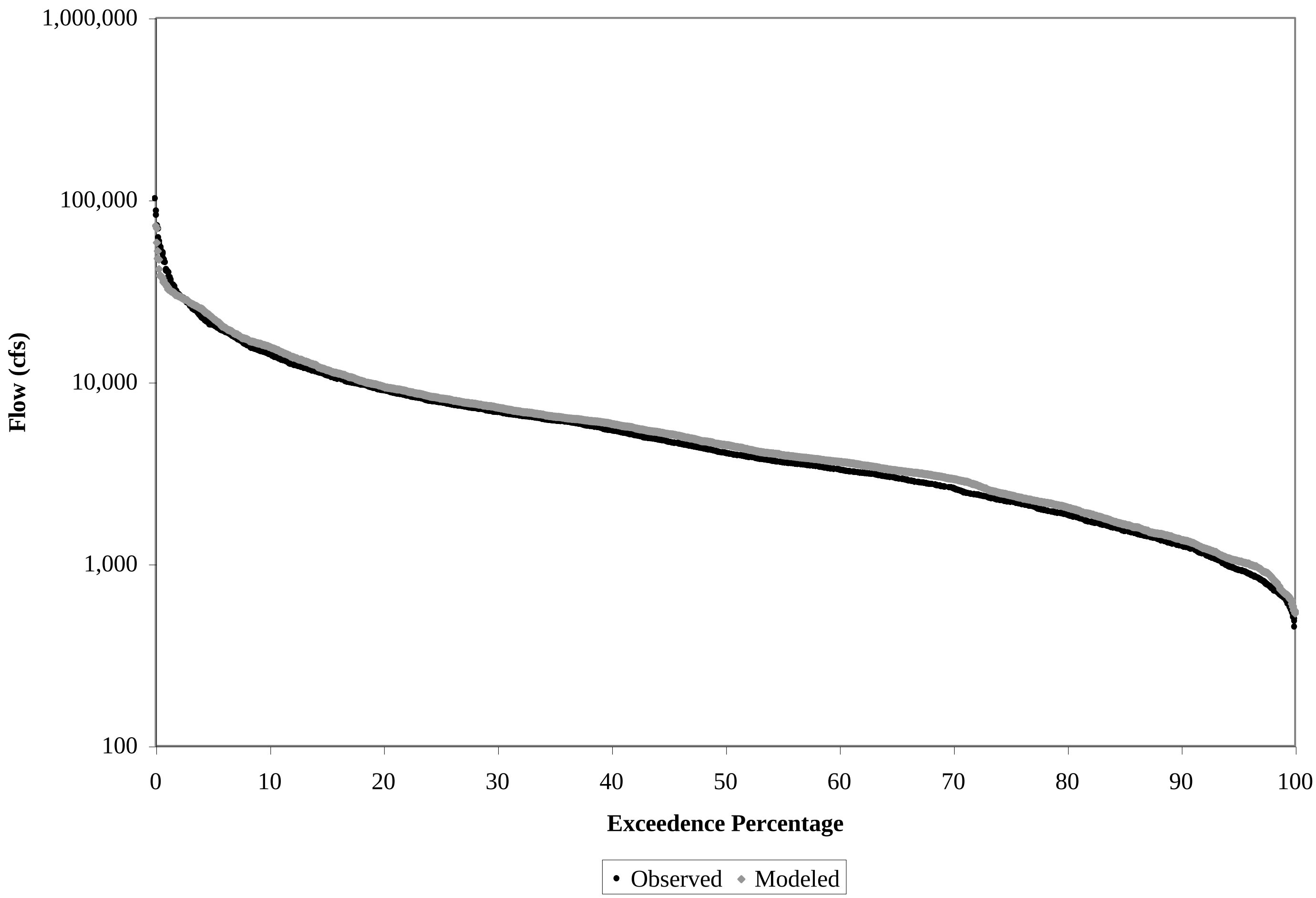

Figure 4.9 **James River flow duration at USGS Gaging Station #02035000 for validation period 10/1/1999 through 12/31/2006 (subwatershed 3).**

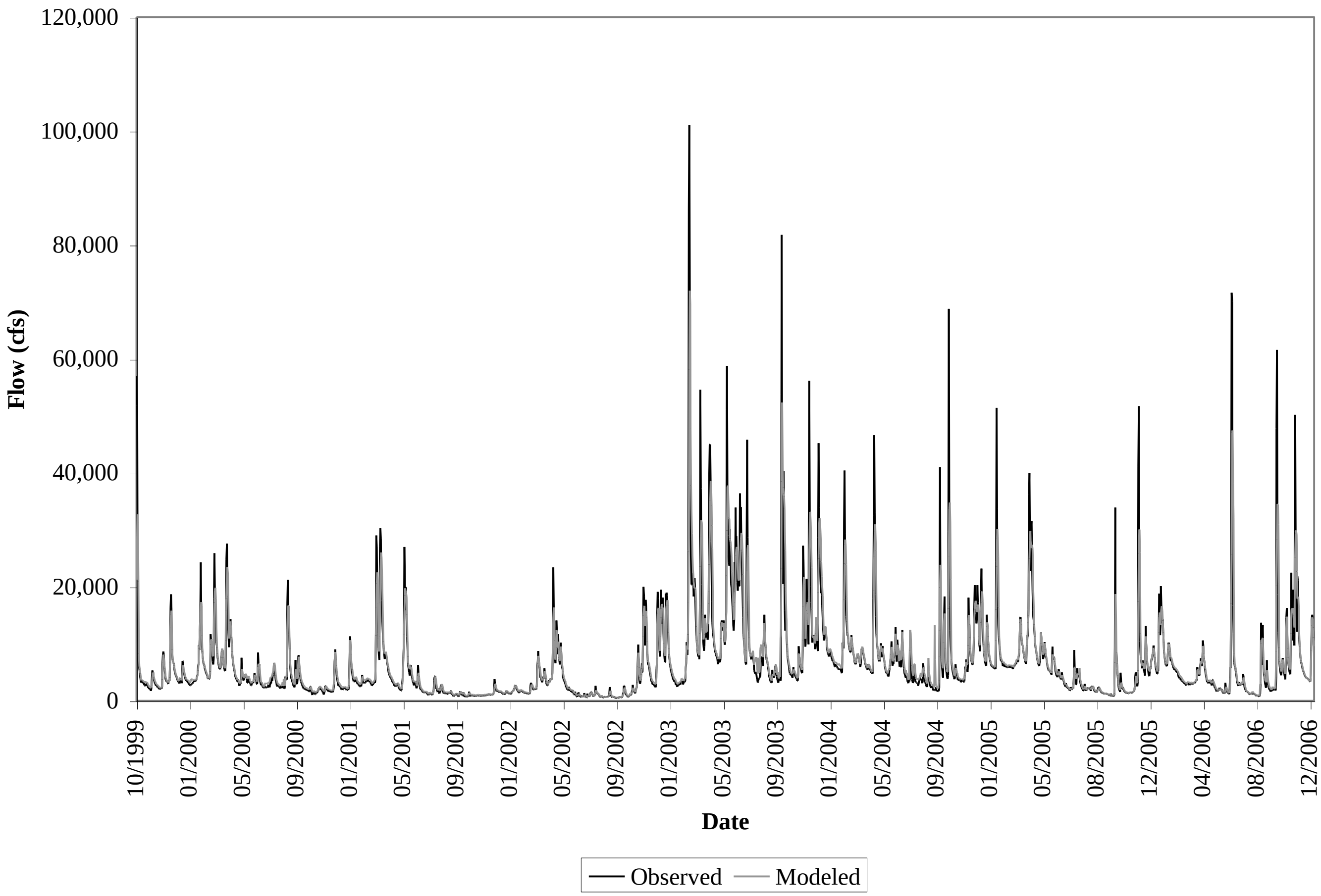

Figure 4.10 Validation results for period 10/1/1999 through 12/31/2006 at USGS Gaging Station #02035000 on the James River (subwatershed 3).

4.7.2 HSPF - Fecal Coliform Water Quality Calibration

Water quality calibration is complicated by a number of factors; first, water quality (fecal coliform) concentrations are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on re-growth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Additionally, the VADEQ data were censored at 8,000 cfu/100ml at times and at 16,000 cfu/100ml at other times. Limited amount of measured data for use in calibration and the practice of censoring both high and low concentrations impede the calibration process.

The HSPF water quality calibration was conducted using data for the time period from 10/1/1999 through 9/30/2003. Four parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), monthly maximum accumulation on land (MON-SQOLIM), the rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP), and the temperature correction coefficient for first-order decay of quality (THFST). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled fecal coliform concentrations was established (Table 4.11).

Table 4.11 Model parameters utilized for water quality calibration.

Parameter	Units	Typical Range	Initial Parameter Estimate	Calibrated Parameter Value
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	0.0 – 3.0E+12	0.0 – 6.1E+13
WSQOP	in/hr	0.05 – 3.00	0.0 – 2.80	0.0 – 3.0
FSTDEC	1/day	0.01 – 10.00	1.0	0.01 – 26.5
THFST	none	1.0 – 2.0	1.07	1.0 – 2.0

The water land use was given a WSQOP value of zero (0) because it represents the stream channel and does not have wash-off. The minimum calibrated WSQOP value not considering the water land use was 0.16, which is within the typical range. The FSTDEC value was increased beyond the typical range for Tuckahoe Creek (subwatershed 26) and Deep Run (subwatershed 27). These subwatersheds have ponds or lakes near the outlets, which allow bacteria to settle to the bottom. To take this into account and provide better bacteria calibration results, the FSTDEC was increased to 26.5 for Tuckahoe Creek, to 14.4 for Deep Run, and to 11.0 and 20.0 for segments of the James River. All other subwatersheds were calibrated using FSTDEC values within the typical range.

Figures 4.11 through 4.27 show the results of water quality calibration. Monitored values are an instantaneous snapshot of the bacteria level, whereas the modeled values are daily averages based on hourly modeling. The monitored values may have been sampled at the highest concentration of the day and thus correctly appear above the modeled daily average. Although the range of modeled daily average values may not reach every instantaneous monitored value, the modeled data follows the trend of monitored data, and typically includes the monitored extremes.

The bacteria concentrations at each station in the study area, except the No Name Creek stations, were calibrated using the four parameters noted above in Table 4.10. The single sample violation percentage from the model output of No Name Creek was initially 0%. The calibrated model values were still well below the estimated 83%, after using the four typical calibration parameters within HSPF. In order to observe the most dominate source of bacteria in No Name Creek, a sensitivity analysis was performed within subwatershed 23. The following bacteria source groups were doubled: human, livestock, and wildlife direct sources; residential/urban, agricultural, and natural land-based sources. As expected, based on BST data, watershed visits, and knowledge about the area, No Name Creek is most sensitive to changes in the direct human waste load. Possible sources of direct human waste are straight pipes from residential homes, illicit sewage connections to the stormwater collection system, sewer leakages, and unreported sewer overflows. Based on the results of the sensitive analysis and the prior information about the watershed, the human bacteria sources were increased by 3.0 times in order to calibrate the bacteria levels in No Name Creek. Figure 4.25, Table 4.12 and Table 4.13 show the results of the No Name Creek calibration.

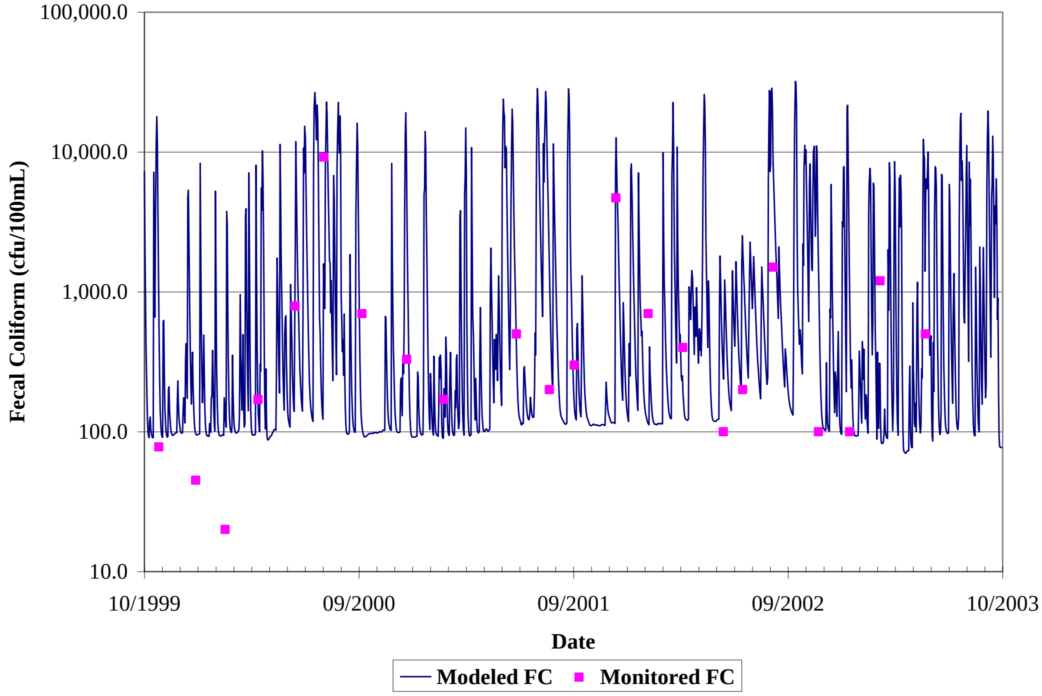

Figure 4.11 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-ALM000.42 in subwatershed 18 in the Almond Creek impairment.

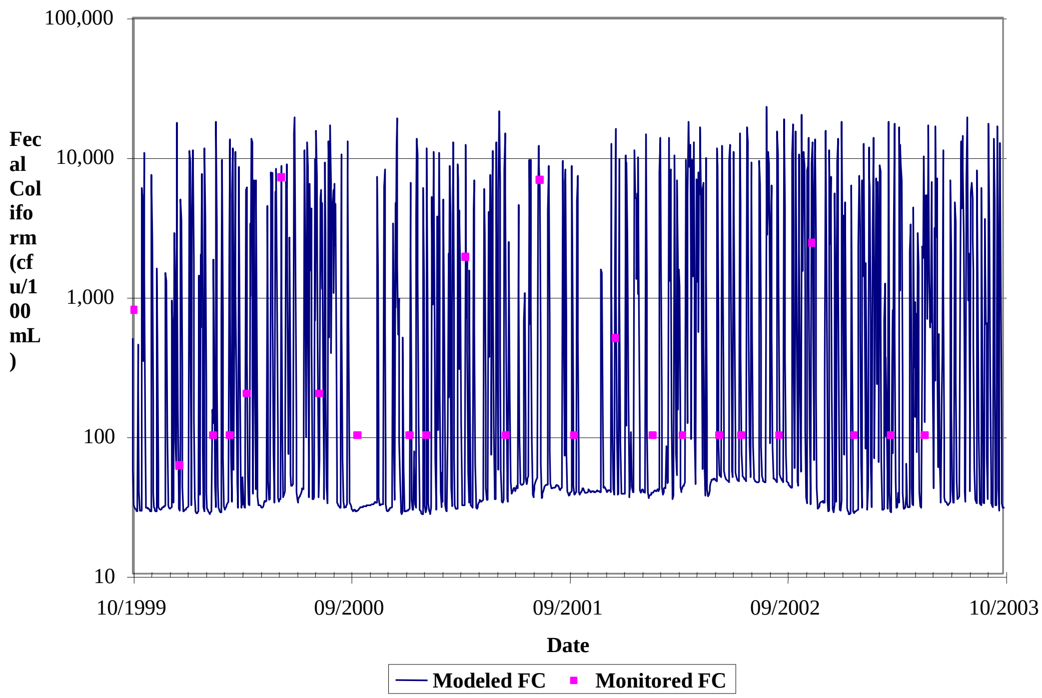

Figure 4.12 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-BOR-001.73 in subwatershed 16 in the Bernards Creek impairment.

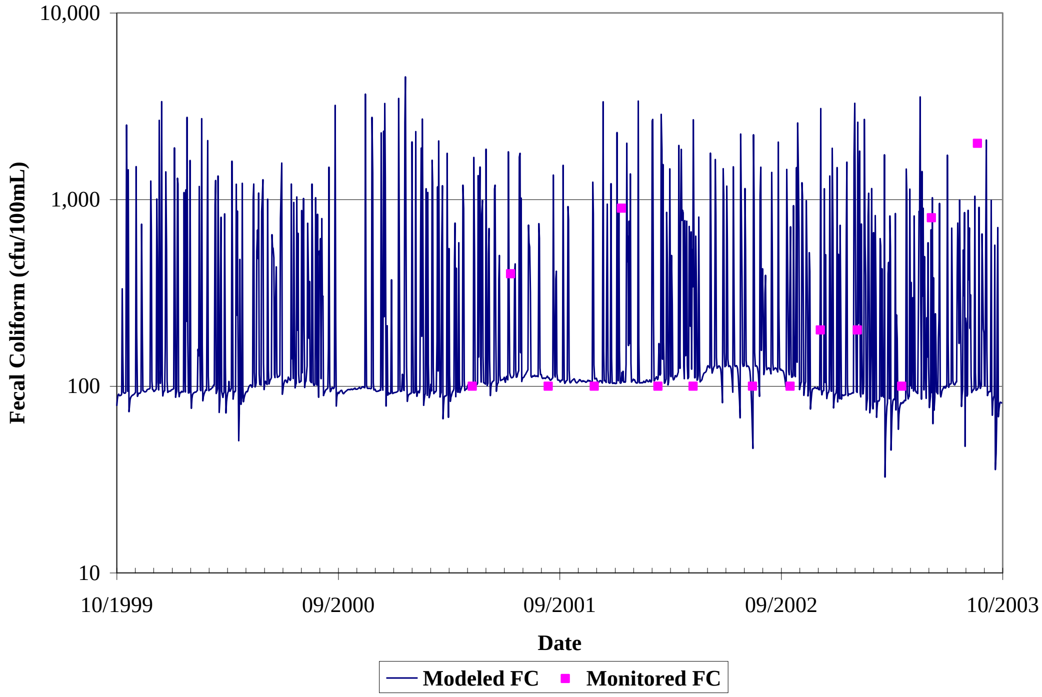

Figure 4.13 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-FAC009.46 in subwatershed 20 in Falling Creek (not impaired).

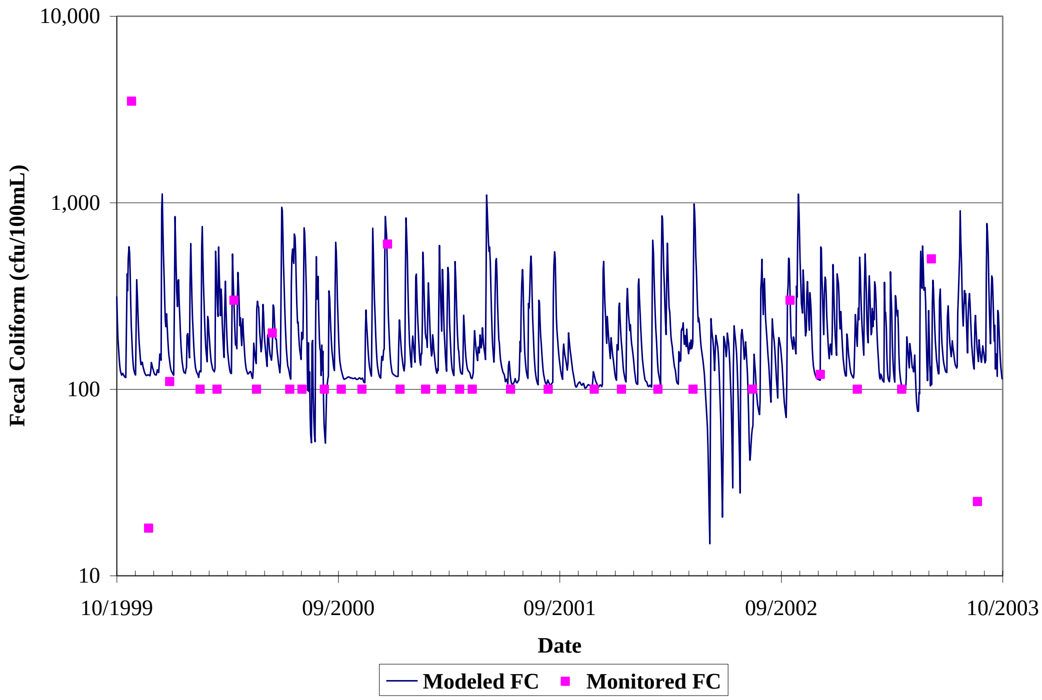

Figure 4.14 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-FAC000.85 in subwatershed 22 in the Falling Creek impairment.

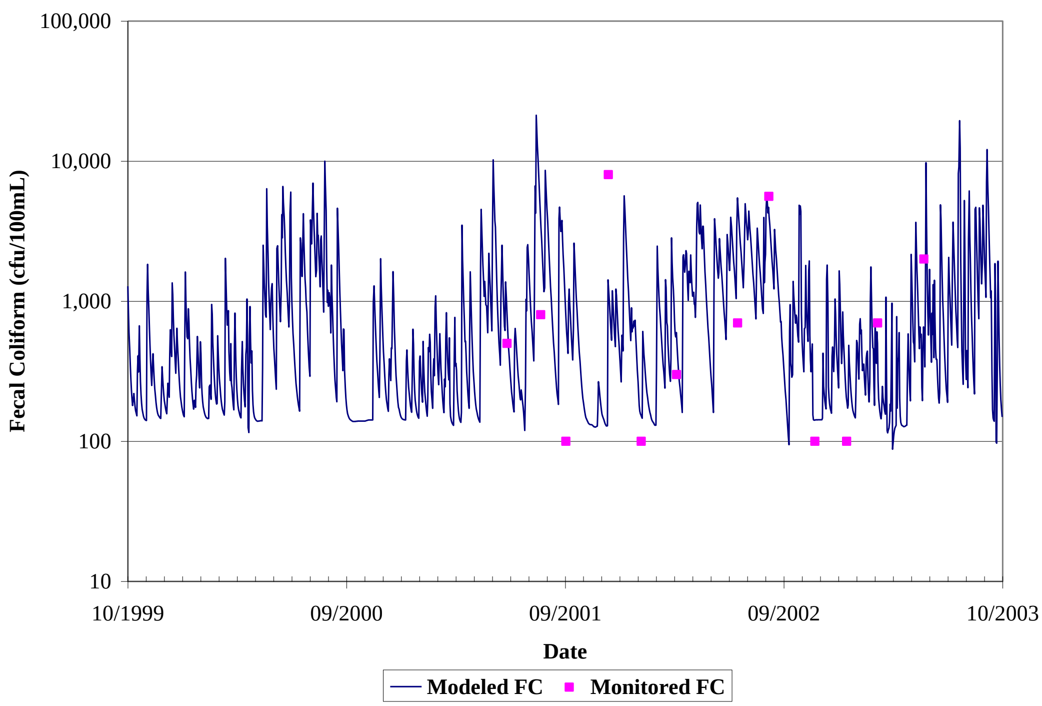

Figure 4.15 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-GIL001.00 in subwatershed 40 in the Gillie Creek impairment.

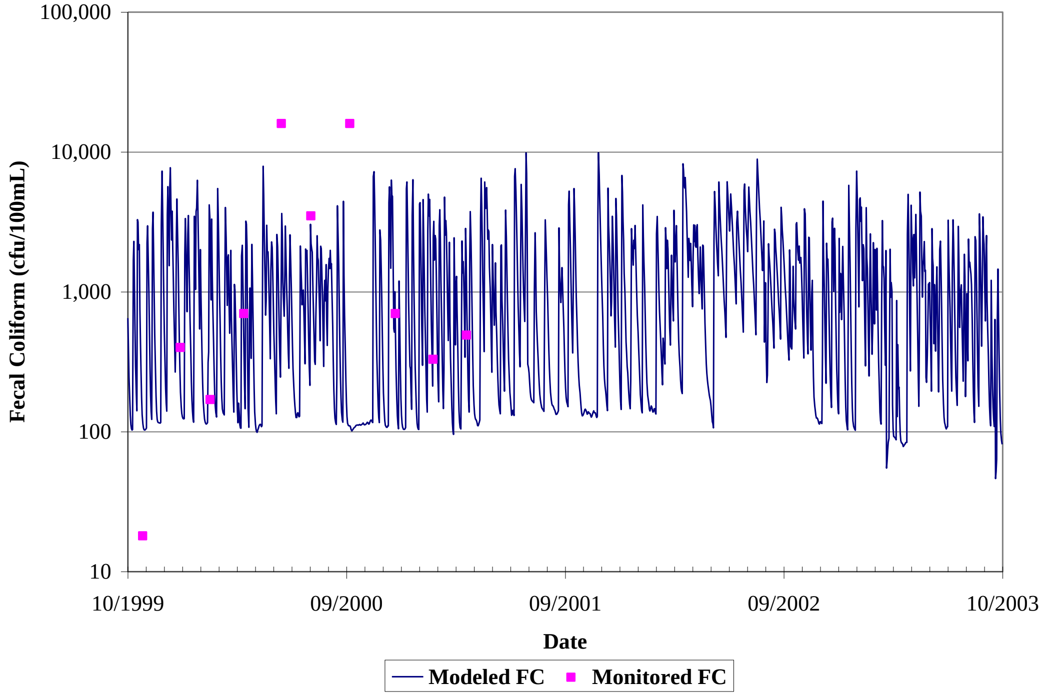

Figure 4.16 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-GOD000.77 in subwatershed 19 in the Goode Creek impairment.

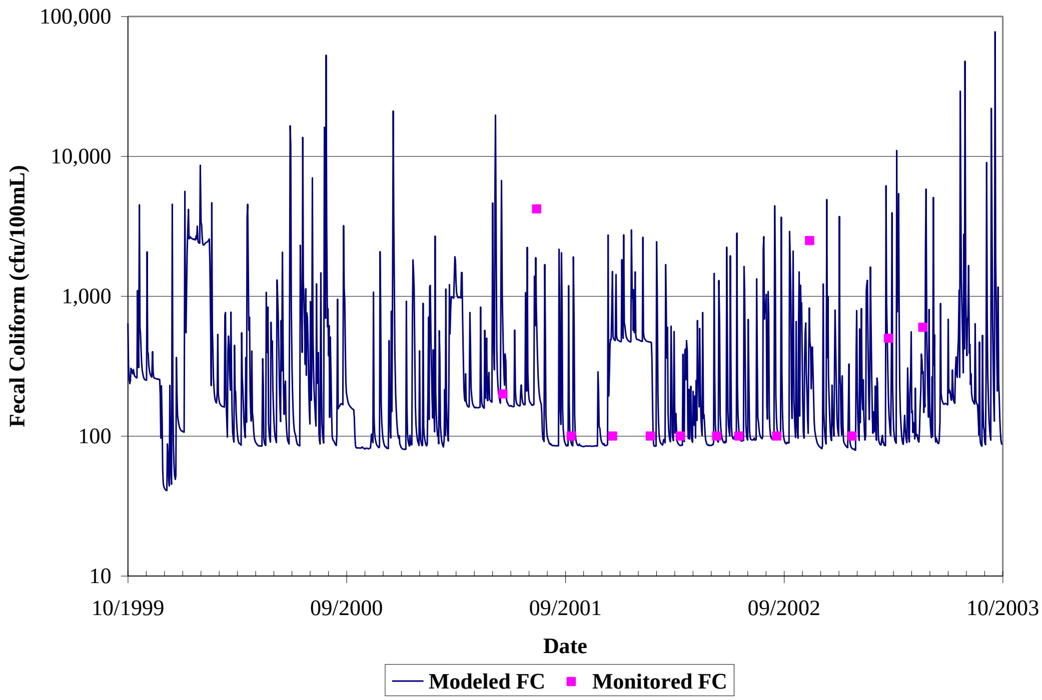

Figure 4.17 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-JMS127.50 in subwatershed 1 in the James River (not impaired).

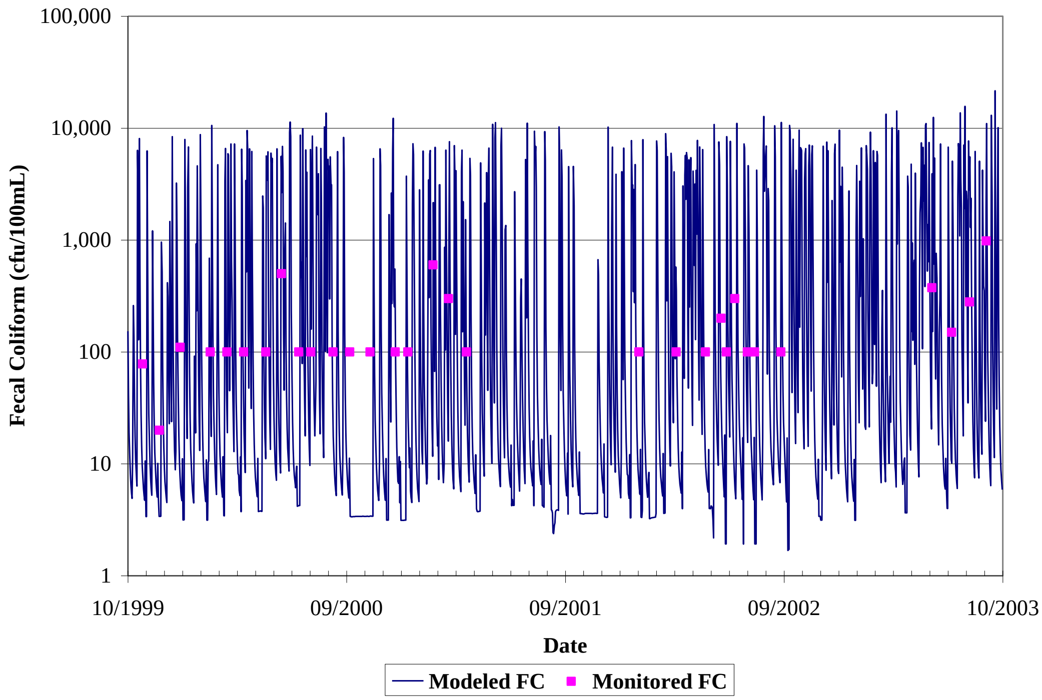

Figure 4.18 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-TKO004.69 in subwatershed 26 in Tuckahoe Creek (impaired, but not included in this project).

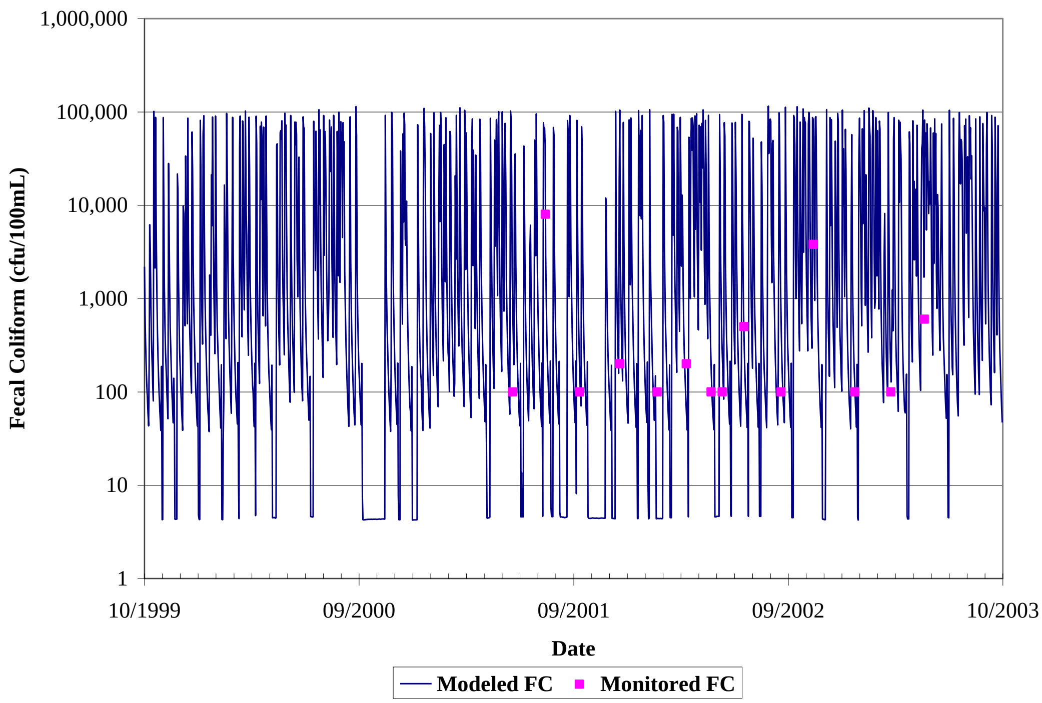

Figure 4.19 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-DPR001.00 in subwatershed 28 in Deep Run (impaired, but not included in this project).

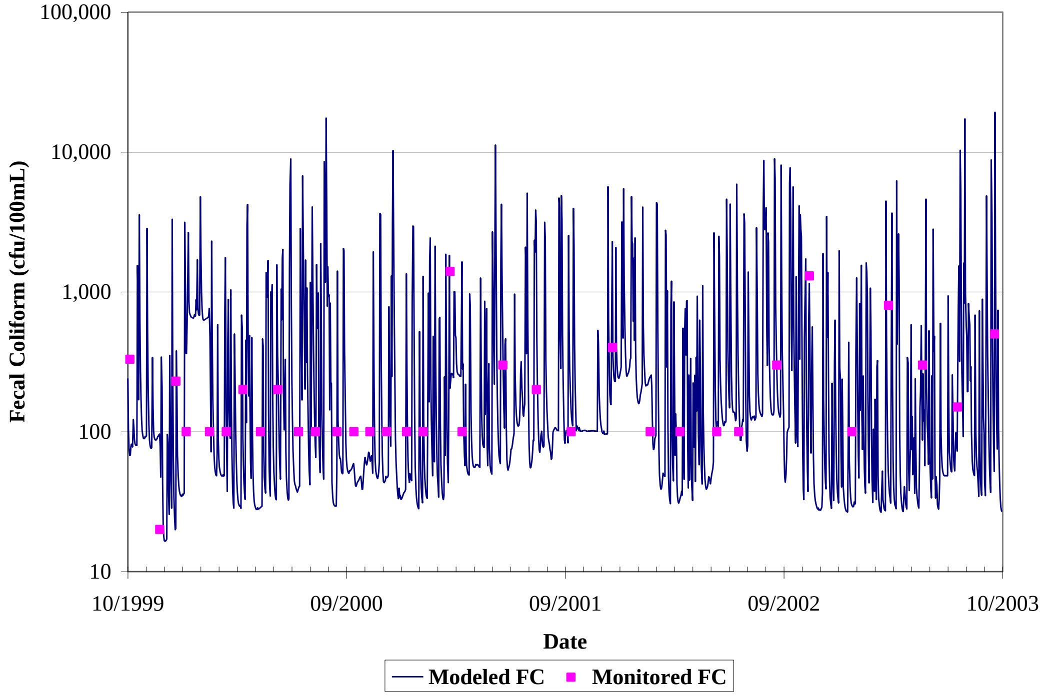

Figure 4.20 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-JMS117.35 in subwatershed 3 in the James River (upper) impairment.

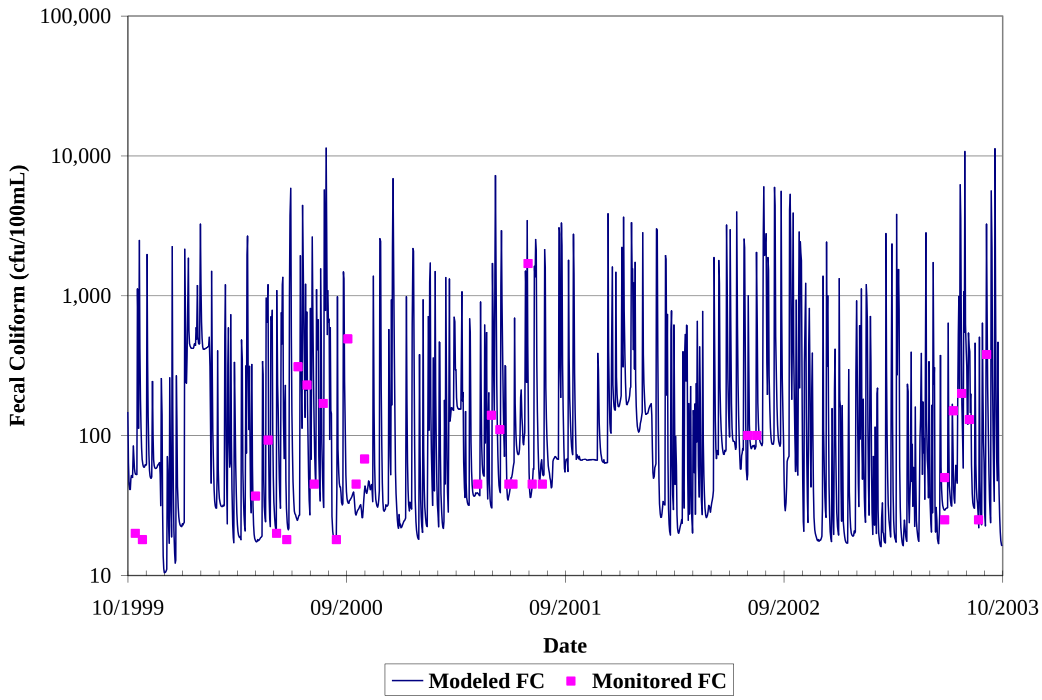

Figure 4.21 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-JMS115.29 in subwatershed 5 in the James River (lower) impairment.

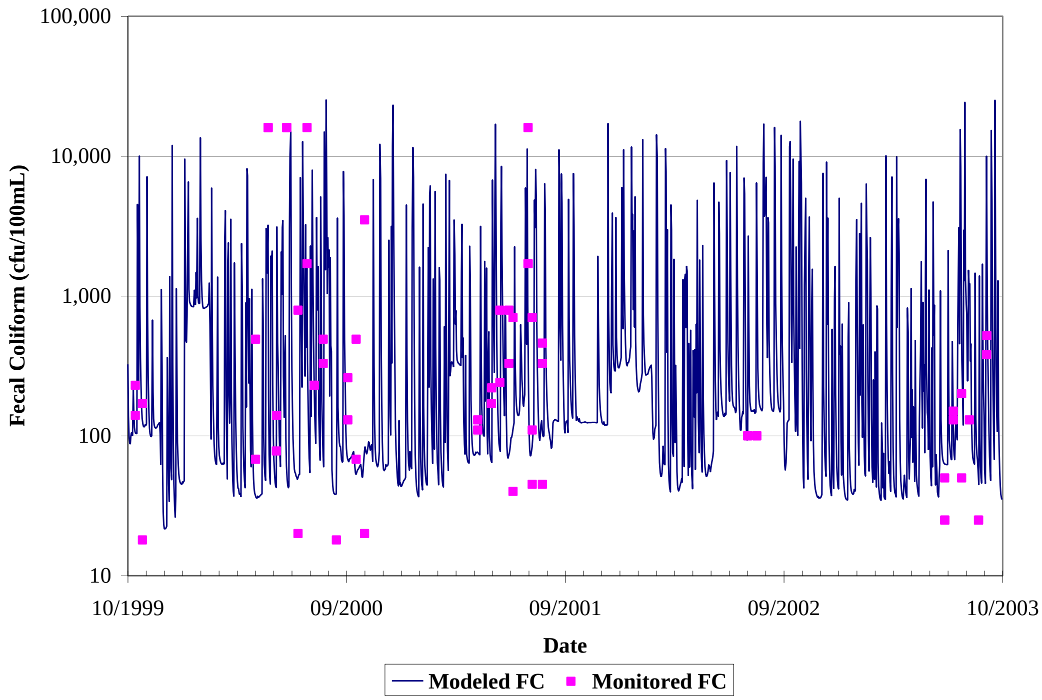

Figure 4.22 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ stations 2-JMS112.33 and 2-JMS112.37 in subwatershed 7 in the James River (lower) impairment.

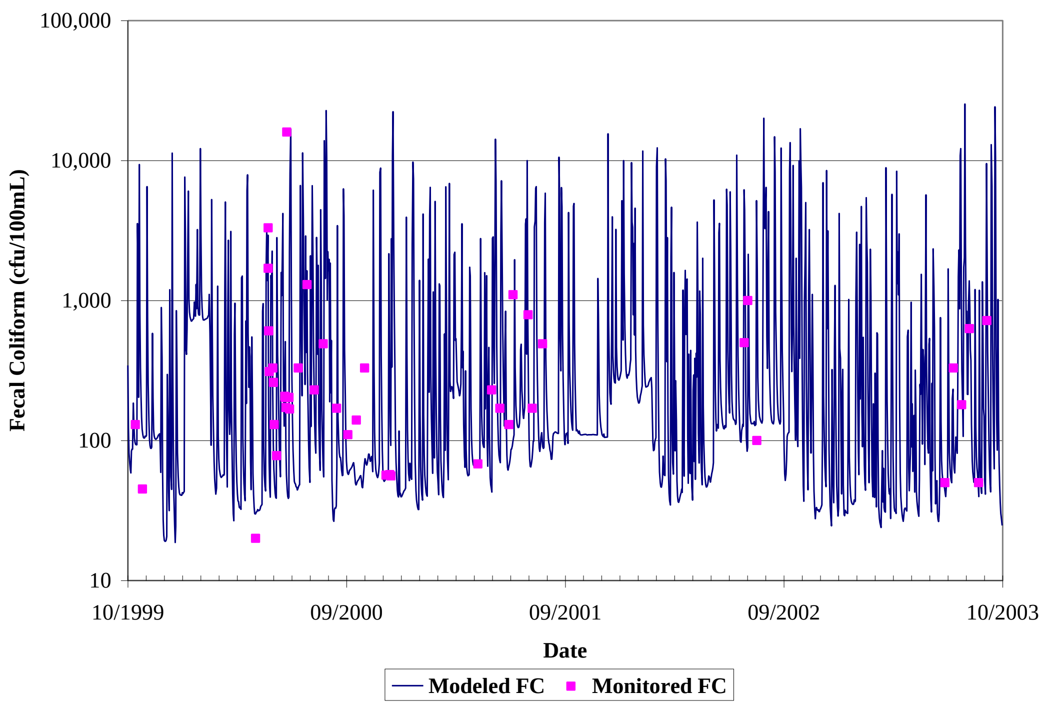

Figure 4.23 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-JMS111.17 in subwatershed 8 in the James River (lower) impairment.

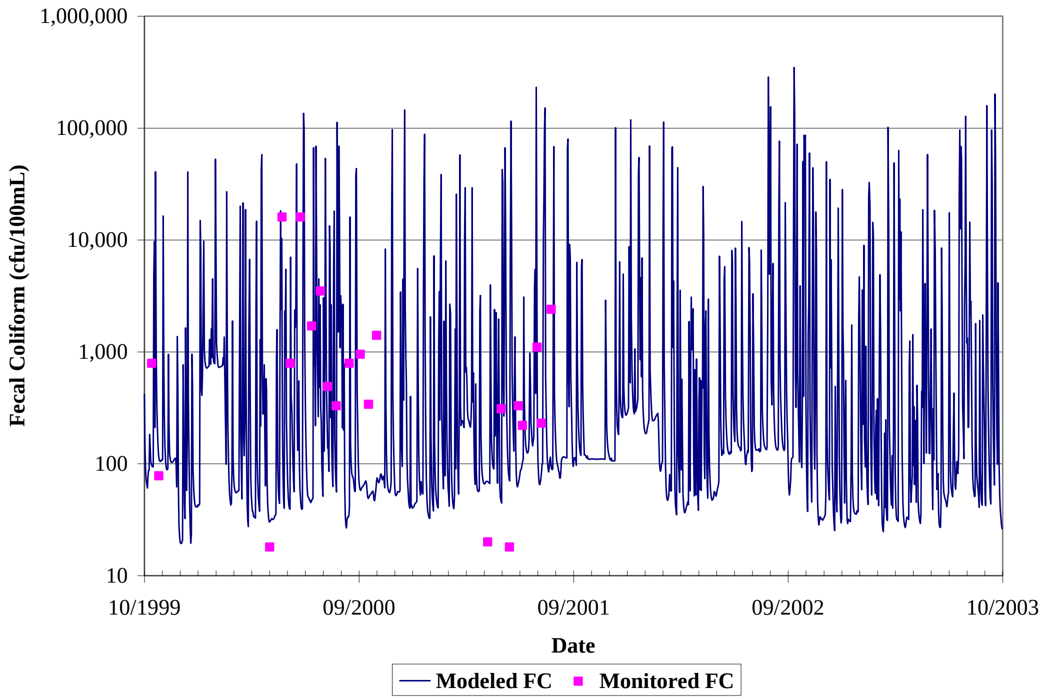

Figure 4.24 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-JMS110.07 in subwatershed 9 in the James River (lower) impairment.

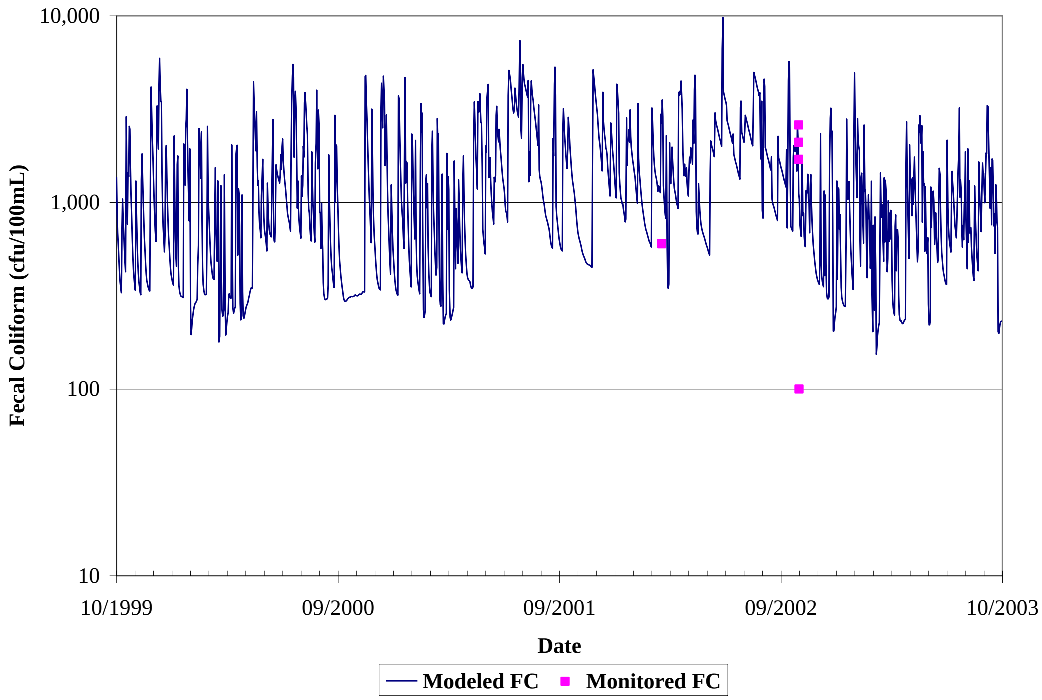

Figure 4.25 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ stations 2-XTC000.08, 2-XUI000.01, 2-XUH000.01, 2-XVL000.04 in subwatershed 23 in the No Name Creek impairment.

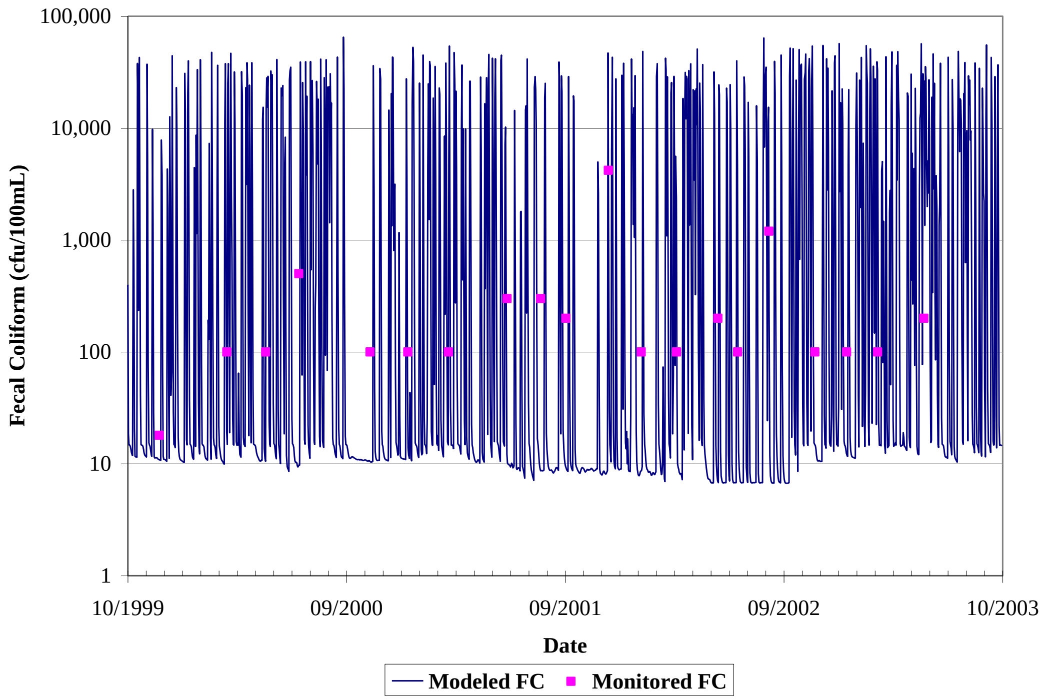

Figure 4.26 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-PWT000.57 in subwatershed 19 in the Powhite Creek impairment.

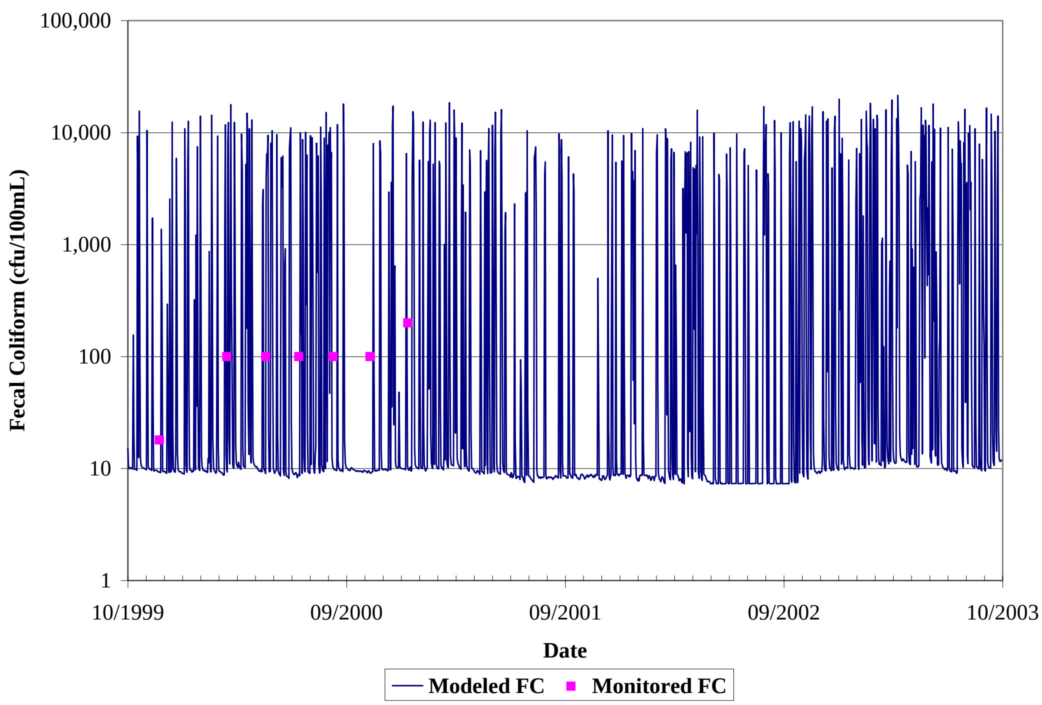

Figure 4.27 Fecal coliform quality calibration results for 10/1/1999 to 9/30/2003 for VADEQ station 2-RDD000.19 in subwatershed 57 in the Reedy Creek impairment.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of fecal coliform concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. Standard error in each observation window was calculated as follows:

$$Standard\ Error = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{(n-1)}}}{\sqrt{n}}$$

where

$$\begin{aligned} observed &= \text{an observed value of fecal coliform} \\ modeled_i &= \text{a modeled value in the 2-day window surrounding the observation} \\ n &= \text{the number of modeled observations in the 2-day window} \end{aligned}$$

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values about an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and, therefore, increases standard error. The mean of all standard errors for each station analyzed was calculated. The standard errors in Table 4.12 range from a low of 9.0 to a high of 404. Even the highest value in this range can be considered quite reasonable when one takes into account the censoring of maximum values that is practiced in the collection of actual water quality samples. The standard error will be biased upwards when an observed high value censored at 8,000 or 16,000 cfu/100mL is compared to a simulated high value that may be an order of magnitude or more above the censor limit. Thus, the standard errors calculated for these impairments are considered an indicator of strong model performance.

Table 4.12 Mean standard error of the fecal coliform calibrated model for the James River-City of Richmond study area watershed (10/1/1999 to 9/30/2003).

Stream	Sub	Station ID(s)	Mean Standard Error	Maximum Simulated Value	Maximum Monitored Value
				-------(cfu/100 mL)-------	
Almond Creek	18	2-ALM000.42	111.1	32,094	9,200
Bernards Creek	16	2-BOR001.73	104.1	22,957	7,100
Falling Creek	20	2-FAC000.85	36.2	4,544	2,000
Falling Creek	22	2-FAC009.46	24.2	1,115	3,500
Gillie Creek	40	2-GIL001.00	188.0	21,292	8,000
Goode Creek	19	2-GOD000.77	341.5	9,865	16,000
James River	1	2-JMS127.50	81.8	77,729	4,200
Tuckahoe Creek	26	2-TKO004.69	19.3	21,614	980
Deep Run	27	2-DPR001.00	404.4	115,334	8,000
James River	3	2-JMS117.35	21.0	19,234	1,400
James River	5	2-JMS115.29	16.3	11,383	1,700
James River	7	2-JMS112.33 and 2-JMS112.37	131.0	28,183	16,000
James River	8	2-JMS111.17	72.9	25,336	16,000
James River	9	2-JMS110.07	369.4	347,665	16,000
No Name	23	2-XTC000.08, 2-XUI000.01, 2-XUH000.01, 2-XVL000.04	90.8	9,769	2,600
Powhite Creek	17	2-PWT000.57	44.9	64,893	4,200
Reedy Creek	57	2-RDD000.19	9.0	21,478	200

Table 4.13 shows the predicted and observed values for the geometric mean and single sample (SS) instantaneous violations for the James River-City of Richmond stream segments. For all stations the maximum percent difference between modeled and monitored geometric means and instantaneous violations were within three standard deviations of the observed data and, therefore, the fecal coliform calibration is acceptable.

Table 4.13 Comparison of modeled and observed fecal coliform calibration results for the James River-City of Richmond study area watershed.

Stream	Subwatershed	Modeled Fecal Coliform 10/1/99 - 9/30/03			Monitored Fecal Coliform 10/1/99 - 9/30/03		
		n	Geometric Mean (cfu/100ml)	SS % violations (cfu/100ml) [1]	*n*	Geometric Mean (cfu/100ml)	SS % violations (cfu/100ml) [1]
Almond Creek	18	1,461	430	39%	22	329	41%
Bernards Creek	16	1,461	195	34%	24	222	25%
Falling Creek	20	1,461	167	19%	14	205	21%
Falling Creek	22	1,461	177	9%	32	125	9%
Gillie Creek	40	1,461	538	54%	12	533	58%
Goode Creek	19	1,461	613	59%	10	783	60%
James River	1	1,461	230	27%	13	234	31%
Tuckahoe Creek	26	1,461	65	26%	31	136	10%
Deep Run	27	1,461	703	53%	14	250	29%
James River	3	1,461	153	23%	34	162	12%
James River	5	1,461	101	19%	31	75	6%
James River	7	1,461	222	28%	62	253	32%
James River	8	1,461	197	27%	45	244	29%
James River	9	1,461	264	30%	22	511	55%
No Name	23	1,461	974	81%	6	833	83%
Powhite Creek	17	1,461	125	33%	20	168	15%
Reedy Creek	57	1,461	47	23%	7	86	0%

[1] SS = single sample instantaneous standard violations (>400 cfu/100mL)

4.7.3 HSPF - Fecal Coliform Water Quality Validation

Fecal coliform water quality model validation was performed on data from 10/1/2003 to 12/31/2006 for all stations listed in Table 4.12. The Almond Creek, Bernards Creek, Gillie Creek, Goode Creek, No Name Creek, Powhite Creek, and Reedy Creek impairments were not validated because fecal coliform data was not available during the time period. Since the calibration and validations of all the other segments were acceptable, and the same techniques were used on all segments, validation was considered not necessary for this segment. The results are shown in Table 4.14. The standard errors in the James River model validation range from 6.49 to 70.8.

Table 4.14 Mean standard error of the fecal coliform validation model for impairments in the James River-City of Richmond study area watershed.

Stream	Subwatershed	Station ID(s)	Mean Standard Error	Max Simulated Value	Max Monitored Value
Falling Creek	20	2-FAC000.85	32.2	4,650	2,000
Falling Creek	22	2-FAC009.46	25.4	915	2,000
Tuckahoe Creek	26	2-TKO004.69	70.8	18,510	1,400
James River	3	2-JMS117.35	9.4	22,288	500
James River	5	2-JMS115.29	6.2	14,277	180
James River	7	2-JMS112.33 2-JMS112.37	7.5	33,473	250
James River	8	2-JMS111.17	15.2	32,100	480

Table 4.15 shows the predicted and observed values for the geometric mean and single sample (SS) instantaneous violations for the appropriate stream segments. The maximum percent difference between modeled and monitored geometric means and instantaneous violations are within two standard deviations of the observed data at each station; therefore, the fecal coliform validation is acceptable (Table 4.15). Graphical comparisons between modeled and observed fecal coliform validation results for the James River-City of Richmond impairments are shown in Figure 4.28 through 4.34.

Table 4.15 Comparison of modeled and observed fecal coliform validation results for the James River-City of Richmond study area watershed.

Stream	Subwatershed	Modeled Fecal Coliform 10/1/99 - 9/30/03			Monitored Fecal Coliform 10/1/99 - 9/30/03		
		n	Geometric Mean (cfu/100ml)	SS % violations (cfu/100ml) [1]	*n*	Geometric Mean (cfu/100ml)	SS % violations (cfu/100ml) [1]
Falling Creek	20	1,187	158	10%	21	121	14%
Falling Creek	22	1,187	186	10%	14	127	14%
Tuckahoe Creek	26	1,187	61	25%	6	83	17%
James River	3	1,187	73	19%	17	62	6%
James River	5	1,187	48	15%	9	68	0%
James River	7	1,187	109	23%	16	55	0%
James River	8	1,187	99	23%	8	121	13%

[1] SS = single sample instantaneous standard violations (>400 cfu/100mL)

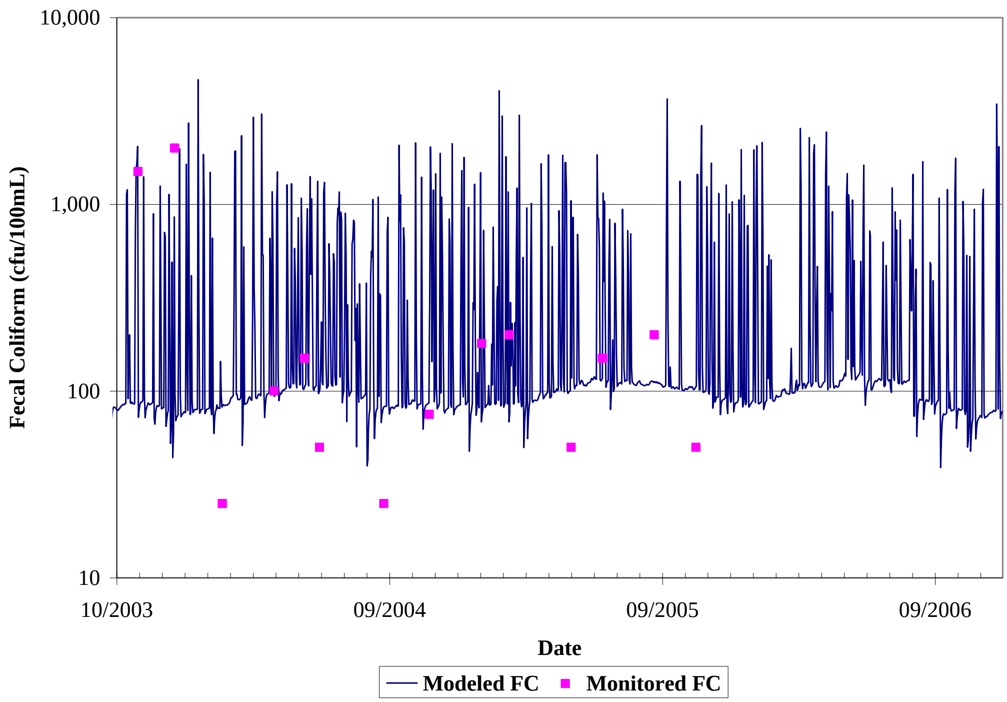

Figure 4.28 Fecal coliform quality validation results for 10/1/2003 to 12/31/2006 for VADEQ station 2-FAC009.46 in subwatershed 20 in Falling Creek (not impaired).

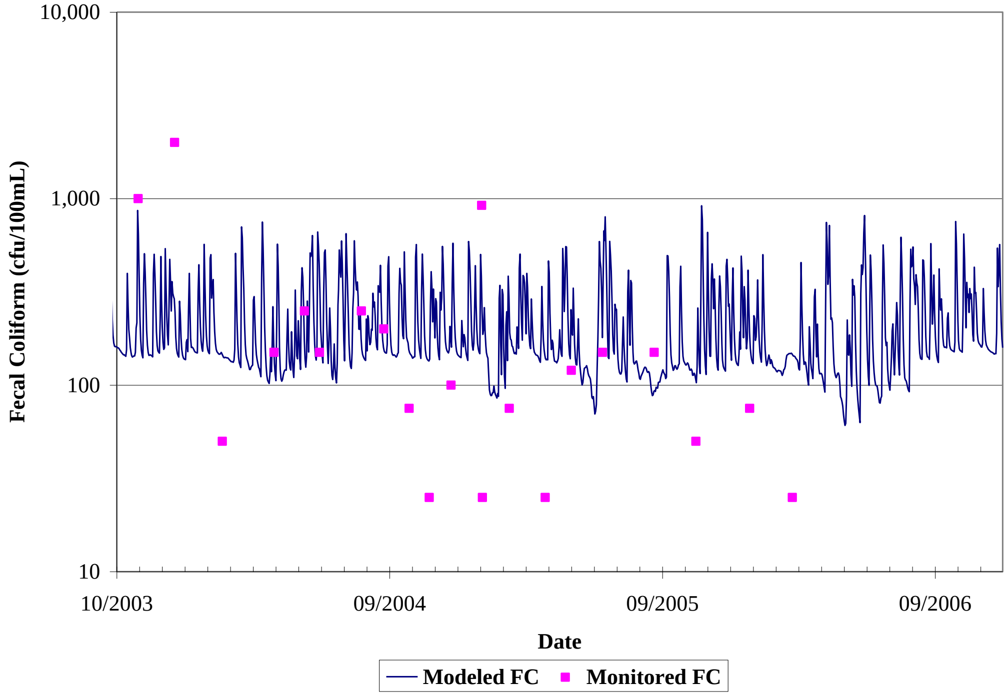

Figure 4.29 Fecal coliform quality validation results for 10/1/2003 to 12/31/2006 for VADEQ station 2-FAC000.85 in subwatershed 22 in Falling Creek.

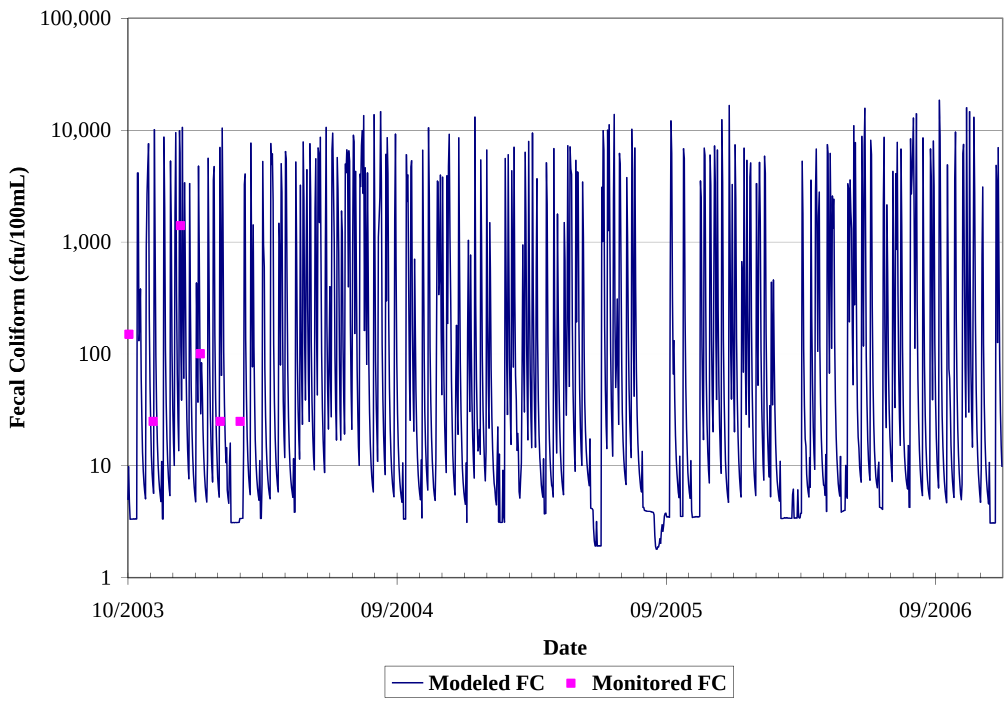

Figure 4.30 Fecal coliform quality validation results for 10/1/2003 to 12/31/2006 for VADEQ station 2-TKO004.69 in subwatershed 26 in Tuckahoe Creek (impaired, but not a part of this study).

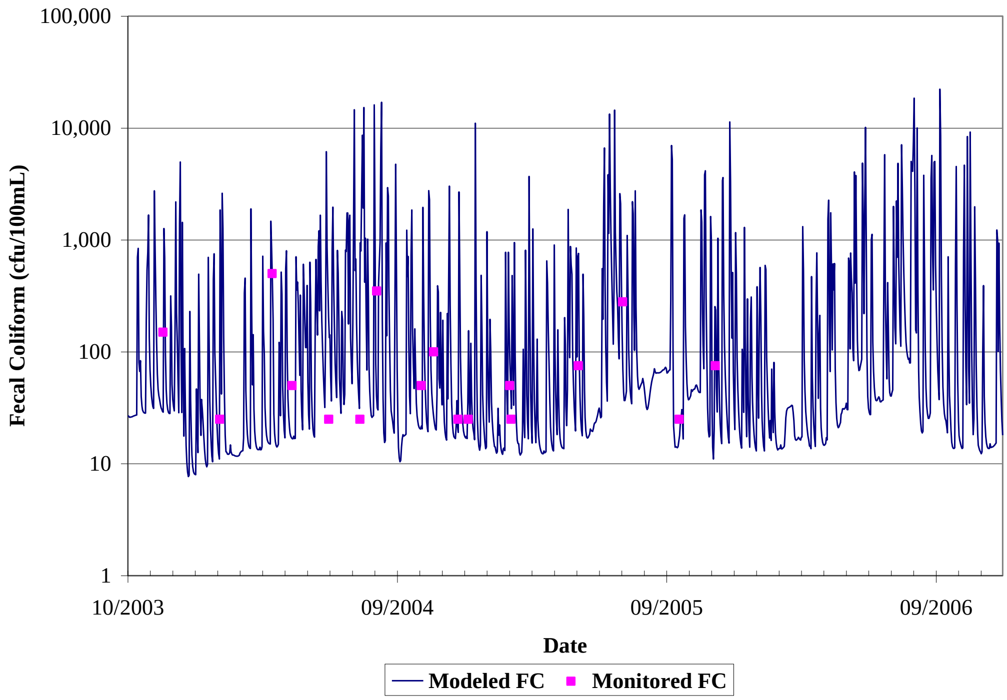

Figure 4.31 Fecal coliform quality validation results for 10/1/2003 to 12/31/2006 for VADEQ station 2-JMS117.35 in subwatershed 3 in the James River (upper).

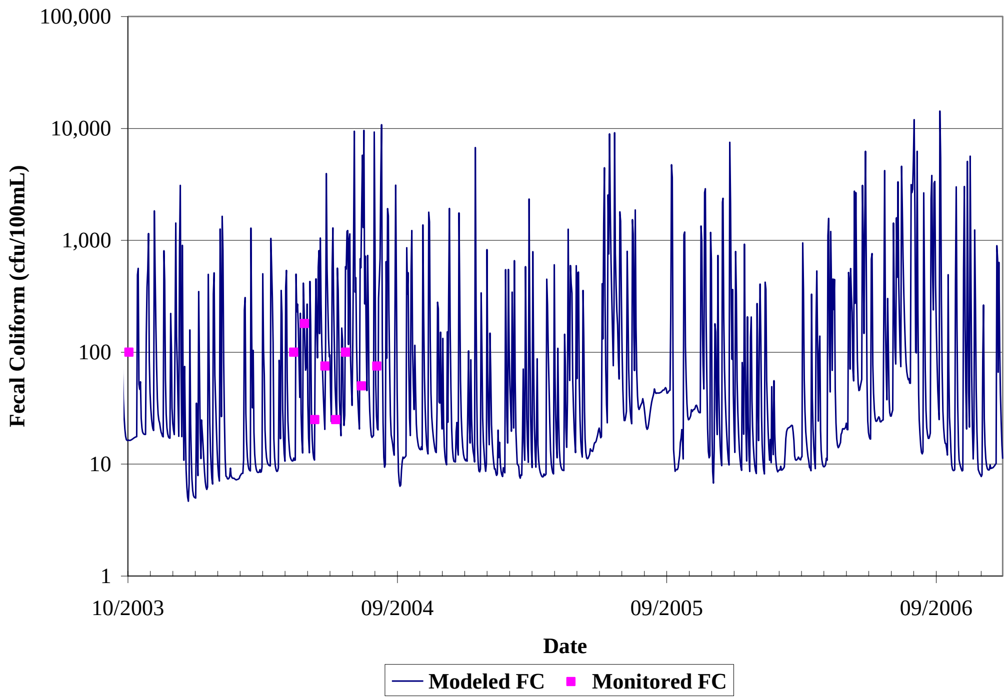

Figure 4.32 Fecal coliform quality validation results for 10/1/2003 to 12/31/2006 for VADEQ station 2-JMS115.29 in subwatershed 5 in the James River (lower).

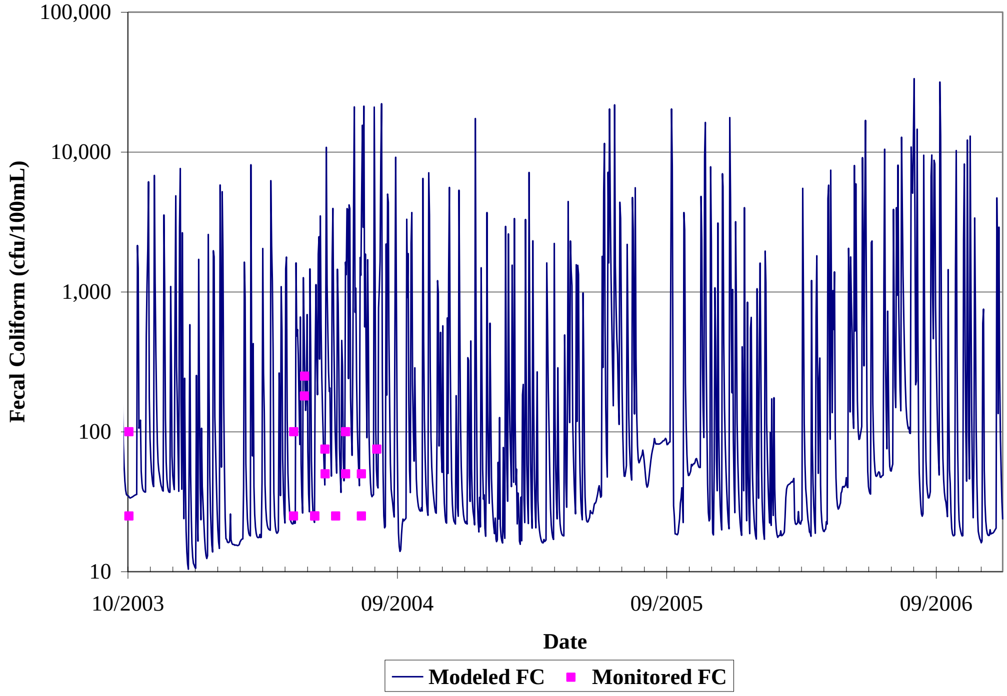

Figure 4.33 Fecal coliform quality validation results for 10/1/2003 to 12/31/2006 for VADEQ stations 2-JMS112.33 and 2-JMS112.37 in subwatershed 7 in the James River (lower).

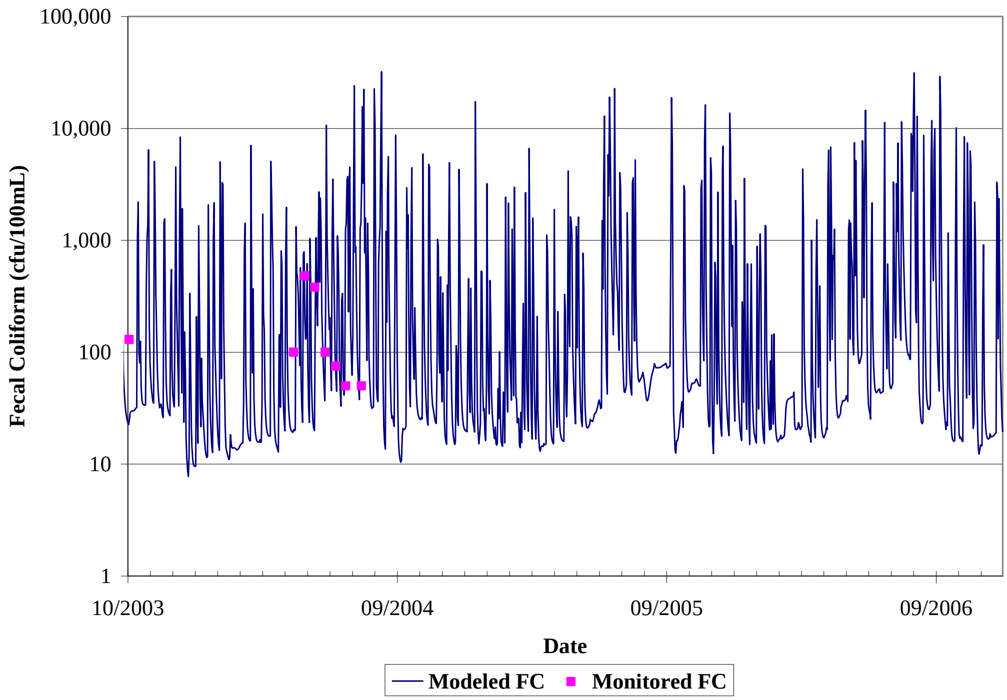

Figure 4.34 Fecal coliform quality validation results for 10/1/2003 to 12/31/2006 for VADEQ station 2-JMS111.17 in subwatershed 8 in the James River (lower).

4.7.4 CE-QUAL-W2 – Hydrology Model setup

Inputs to the CE-QUAL-W2 model consist of output from HSPF model, tributary inputs, tidal inputs, point sources and withdrawals. The break between the riverine and tidally influenced section of the James River occurs at the outlet of subwatershed 9 (Figure 4.2). After the HSPF model was calibrated for hydrology and fecal coliform, the output from subwatershed 9 was reformatted as the upstream James River input to the CE-QUAL-W2 model. HSPF model output was also used from tributaries and reformatted to be input to the tidal CE-QUAL-W2 model. These areas include subwatersheds 18, 19, 22, 23, 29, 30, 31, 32, 33, and 40. The overland runoff was simulated in HSPF for subwatersheds 10-15 as input to the CE-QUAL-W2 model. Point sources were input to the CE-QUAL-W2 model as time series files with flow and bacteria concentrations.

The James River was parsed into branches, which contained multiple segments (Figure 4.35). The cross-sectional information of each segment was input in a bathymetry file. This file contains information on the topography within the stream for every segment. The tidal section of the James River was modeled using 6 branches and 73 segments. This information was obtained from nautical navigation charts (NOAA chart 12252, www.NauticalCharts.noaa.gov) of the James River and from GIS bathymetry data received from DEQ.

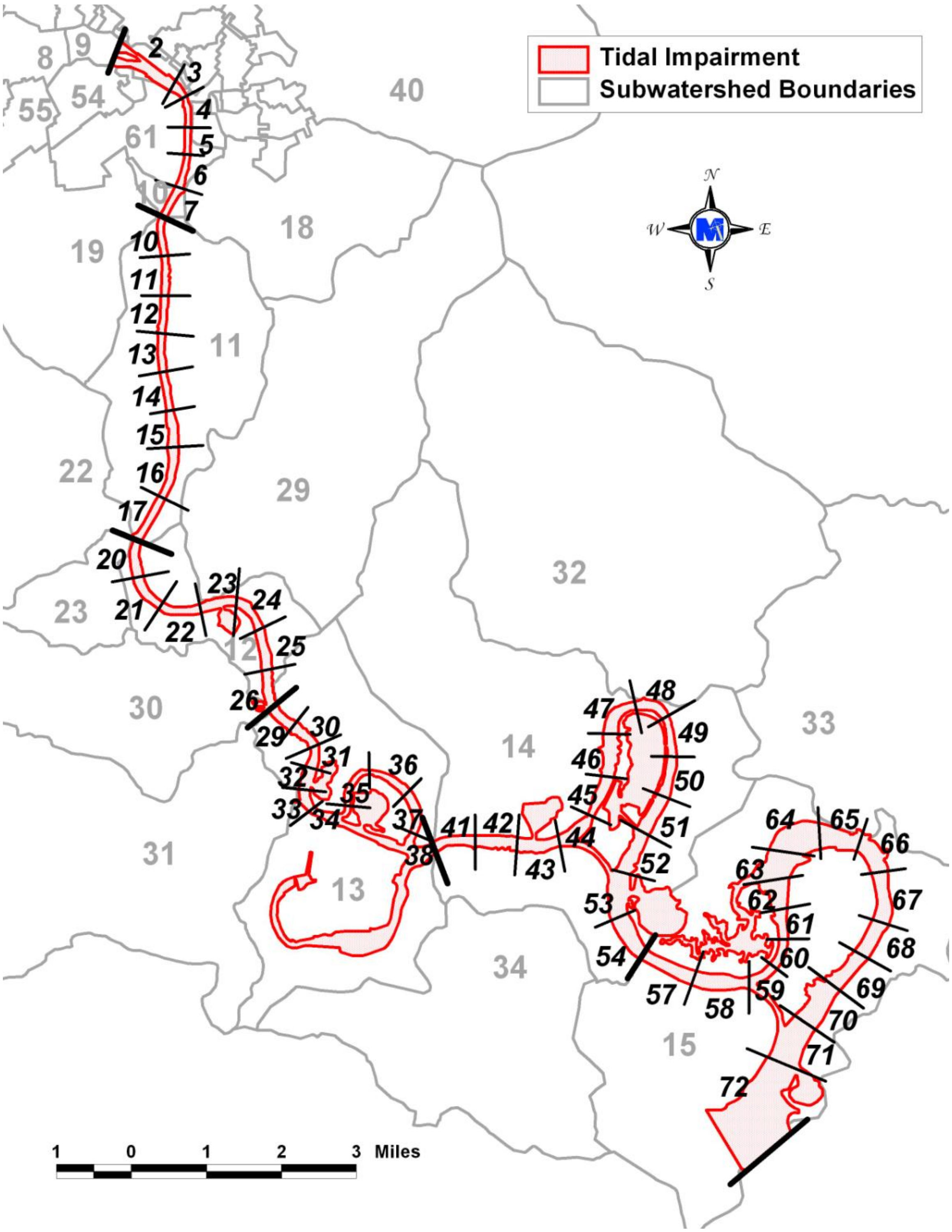

Figure 4.35 CE-QUAL-W2 model branches and segments approximate locations (black numbers) and HSPF model subwatersheds (gray numbers).

An in-stream tidal model like CE-QUAL-W2 requires boundary conditions at the beginning and end of the modeled reach in order to drive the flow of the model. The upstream boundary condition of the James River tidal model was the output of the HSPF model at subwatershed 9. This data included flow (m^3/s) and fecal coliform concentration (cfu/100mL). Upstream boundary files were created for calibration (final calibration of the riverine James River in HSPF), existing conditions (current bacteria sources, allocation time period or rainfall, and zero bacteria source reductions), and allocation (current bacteria sources, allocation time period or rainfall, and James River riverine allocated) model runs.

During bacteria calibration, the downstream bacteria boundary condition for the James River tidal segment was fecal coliform concentration data from DEQ station JMS075.04. For existing conditions and allocation the bacteria concentration entering the James River tidal segment from downstream was set at 200 cfu/100mL fecal coliform. This concentration is the equivalent to the *E. coli* geometric mean standard of 126 cfu/100mL. Setting the boundary condition at the standard is part of the margin of safety explained in Section 5.1. The downstream flow boundary condition was based on tide levels at the NOAA tide station Bermuda Hundred.

4.7.5 CE-QUAL-W2 - Fecal Coliform Water Quality Calibration

Water quality calibration is complicated by a number of factors; first, water quality (fecal coliform) concentrations are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on re-growth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Additionally, the VADEQ data were censored at 8,000 cfu/100ml at times and at 16,000 cfu/100ml at other times. Limited amount of measured data for use in calibration and the practice of censoring both high and low concentrations impede the calibration process.

The water quality calibration for the CE-QUAL-W2 model was conducted using data for the time period from 10/6/1999 through 10/5/2000. There is only one parameter available for calibration adjustment: in-stream first-order decay rate (FSTDEC). The CE-QUAL-W2 model output was calibrated for fecal coliform at the following stations in the James River: JMS109.39, JMS107.51, JMS104.16, JMS103.15, JMS101.03, JMS099.30, JMS097.41, JMS094.96, JMS093.21, JMS091.00, JMS087.01, and JMS080.76. The final calibrated value of FSTDEC was 3.0/day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of fecal coliform concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. Standard error in each observation window was calculated as follows:

$$Standard\ Error = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{(n-1)}}}{\sqrt{n}}$$

where

$$\begin{aligned} observed &= \text{an observed value of fecal coliform} \\ modeled_i &= \text{a modeled value in the 2-day window surrounding the observation} \\ n &= \text{the number of modeled observations in the 2-day window} \end{aligned}$$

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values about an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and, therefore, increases standard error. The mean of all standard errors for each station analyzed was calculated. The standard errors in Table 4.16 range from a low of 5.5 to a high of 330.6. Even the highest value in this range can be considered quite reasonable when one takes into account the censoring of maximum values that is practiced in the collection of actual water quality samples. The standard error will be biased upwards when an observed high value censored at 8,000 or 16,000 cfu/100mL is compared to a simulated high value that may be an order of magnitude or more above the censor limit. Thus, the standard errors calculated for these impairments are considered an indicator of strong model performance.

Table 4.16 Mean standard error of the fecal coliform calibrated model for the tidal section of the James River (10/6/1999 to 10/5/2000).

Subwatershed	Station	Mean Standard Error	Maximum Simulated Value	Maximum Monitored Value
			-------(cfu/100 mL)-------	
10	2-JMS109.39	330.6	134,983	16,000
10	2-JMS107.51	253.1	107,197	16,000
11	2-JMS104.16	121.1	128,085	7,400
11	2-JMS103.15	235.3	117,944	16,000
12	2-JMS101.03	195.3	63,544	16,000
13	2-JMS099.30	16.3	32,129	1,400
13	2-JMS097.41	14.7	9,450	790
14	2-JMS094.96	7.6	4,943	330
14	2-JMS093.21	16.1	4,403	1,100
14	2-JMS091.00	8.5	4,345	490
15	2-JMS087.01	11.1	487	1,200
15	2-JMS080.76	5.5	647	220
15	2-JMS078.99	8.2	454	490

Table 4.17 shows the predicted and observed values for the geometric mean and single sample (SS) instantaneous violations for the James River-City of Richmond stream segments. For all stations the maximum percent difference between modeled and monitored geometric means and instantaneous violations were within three standard deviations of the observed data and, therefore, the fecal coliform calibration is acceptable.

Table 4.17 Comparison of modeled and observed fecal coliform calibration results for tidal section of the James River.

Station	Subwatershed	Modeled Fecal Coliform 10/6/99 – 10/5/00			Monitored Fecal Coliform 10/6/99 – 10/5/00		
		n	Geometric Mean (cfu/100ml)	SS % violations (cfu/100ml) [1]	*n*	Geometric Mean (cfu/100ml)	SS % violations (cfu/100ml) [1]
2-JMS109.39	10	365	276	37%	12	317	42%
2-JMS107.51	10	365	247	36%	12	341	42%
2-JMS104.16	11	365	183	32%	12	146	17%
2-JMS103.15	11	365	125	23%	12	210	33%
2-JMS101.03	12	365	48	15%	12	136	25%
2-JMS099.30	13	365	21	11%	23	108	9%
2-JMS097.41	13	365	11	7%	12	90	8%
2-JMS094.96	14	365	12	6%	12	60	0%
2-JMS093.21	14	365	12	6%	12	77	8%
2-JMS091.00	14	365	12	5%	12	49	8%
2-JMS087.01	15	365	11	1%	24	80	8%
2-JMS080.76	15	365	8	1%	12	49	0%
2-JMS078.99	15	365	7	0%	12	52	8%

[1] SS = single sample instantaneous standard violations (>400 cfu/100mL)

Figures 4.36 through 4.48 show the results of water quality calibration. Monitored values are an instantaneous snapshot of the bacteria level, whereas the modeled values are daily averages based on hourly modeling. The monitored values may have been sampled at the highest concentration of the day and thus correctly appear above the modeled daily average, or the opposite could be true. Although the range of modeled daily average values may not reach every instantaneous monitored value, the modeled data follows the trend of monitored data, and includes the monitored extremes.

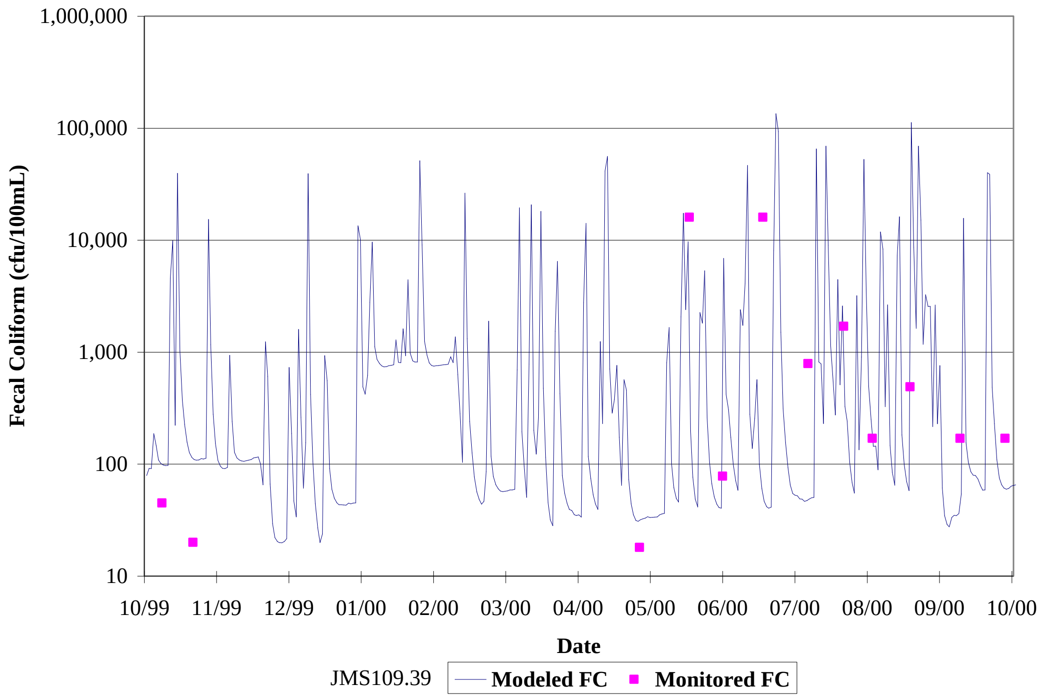

Figure 4.36 Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS109.39 in subwatershed 10 in the James River tidal impairment.

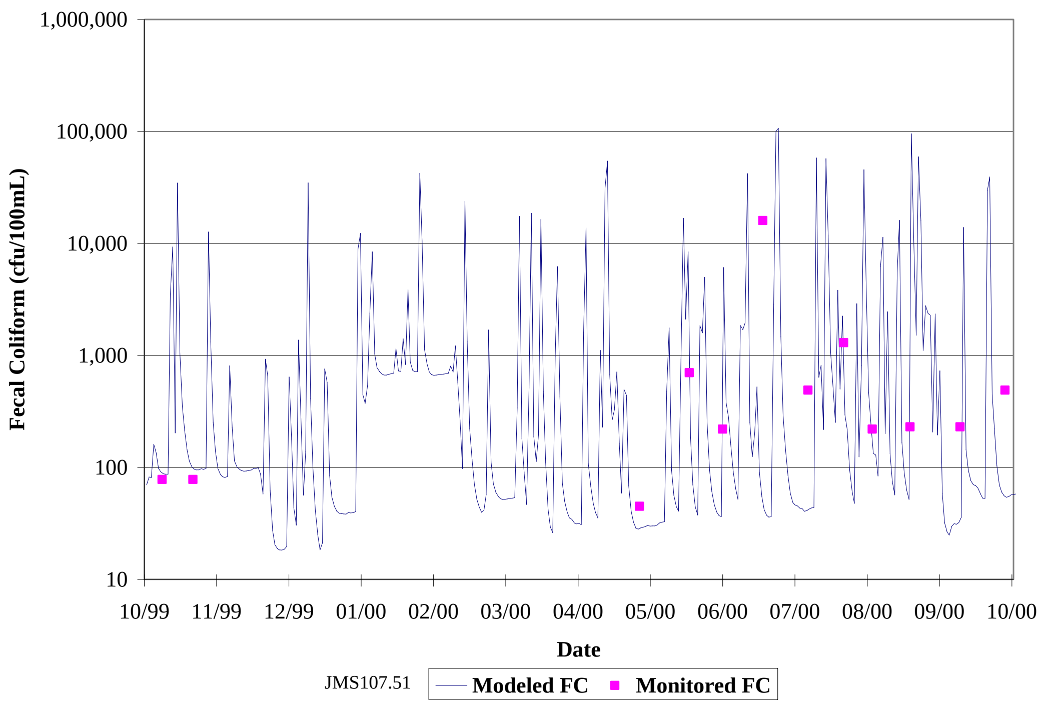

Figure 4.37 Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS107.51 in subwatershed 10 in the James River tidal impairment.

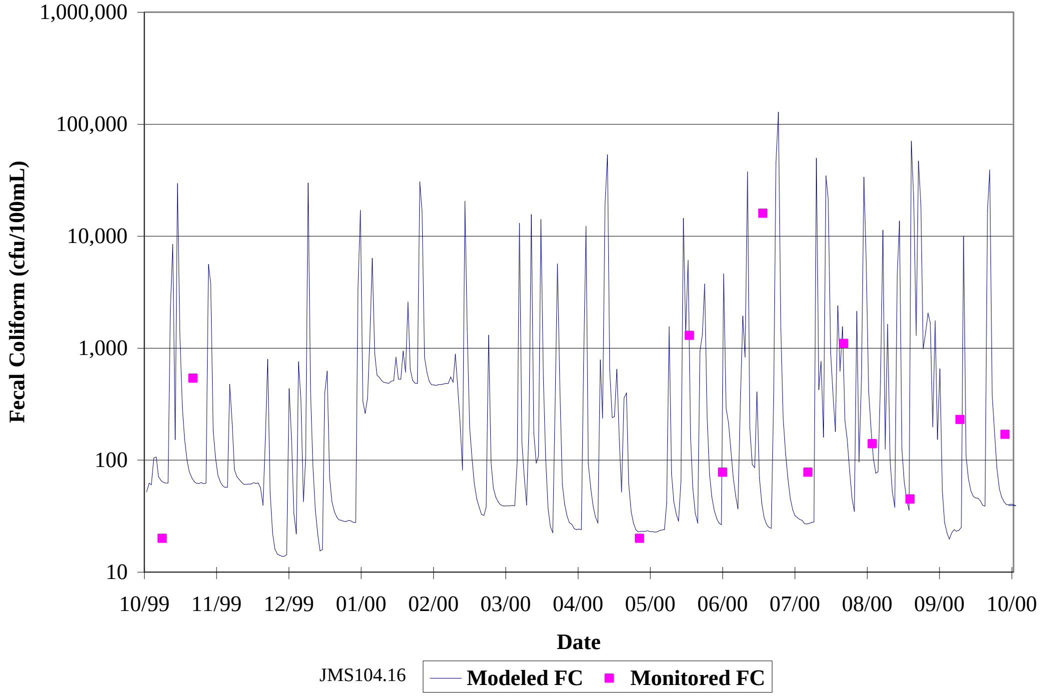

Figure 4.38 Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS104.16 in subwatershed 11 in the James River tidal impairment.

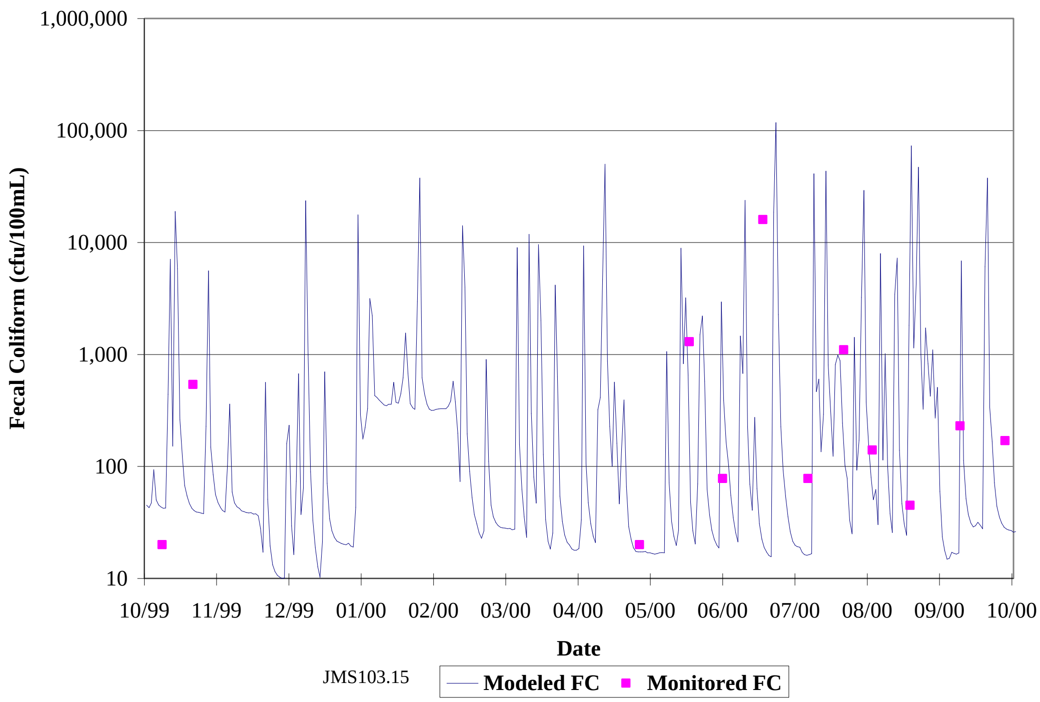

Figure 4.39 Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS103.15 in subwatershed 11 in the James River tidal impairment.

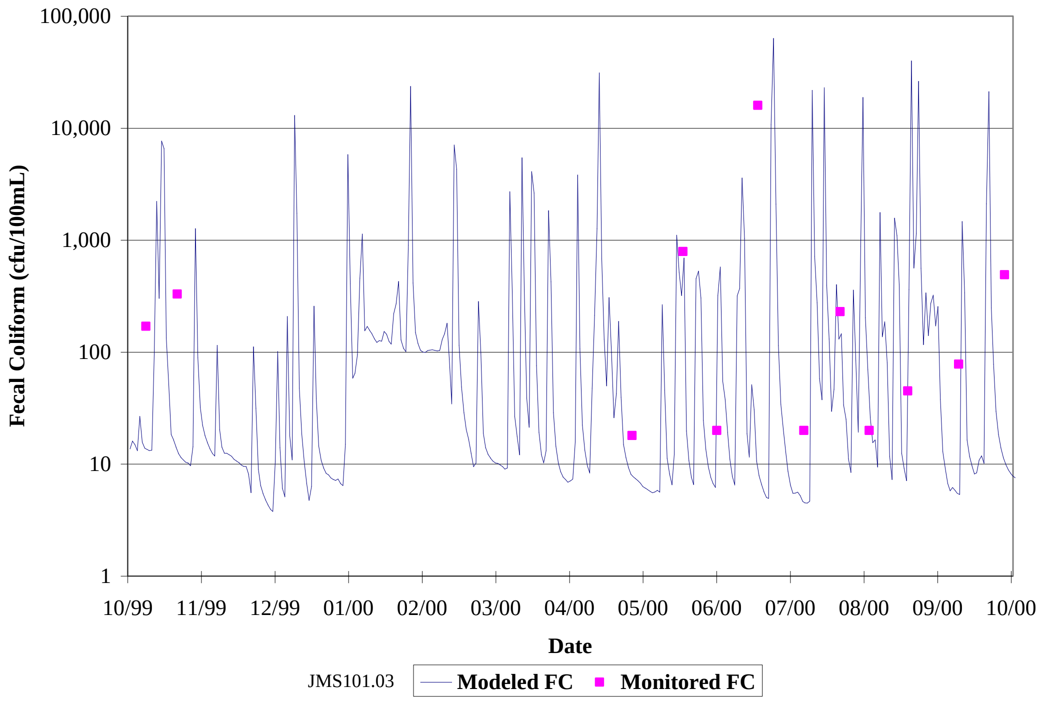

Figure 4.40 Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS101.03 in subwatershed 12 in the James River tidal impairment.

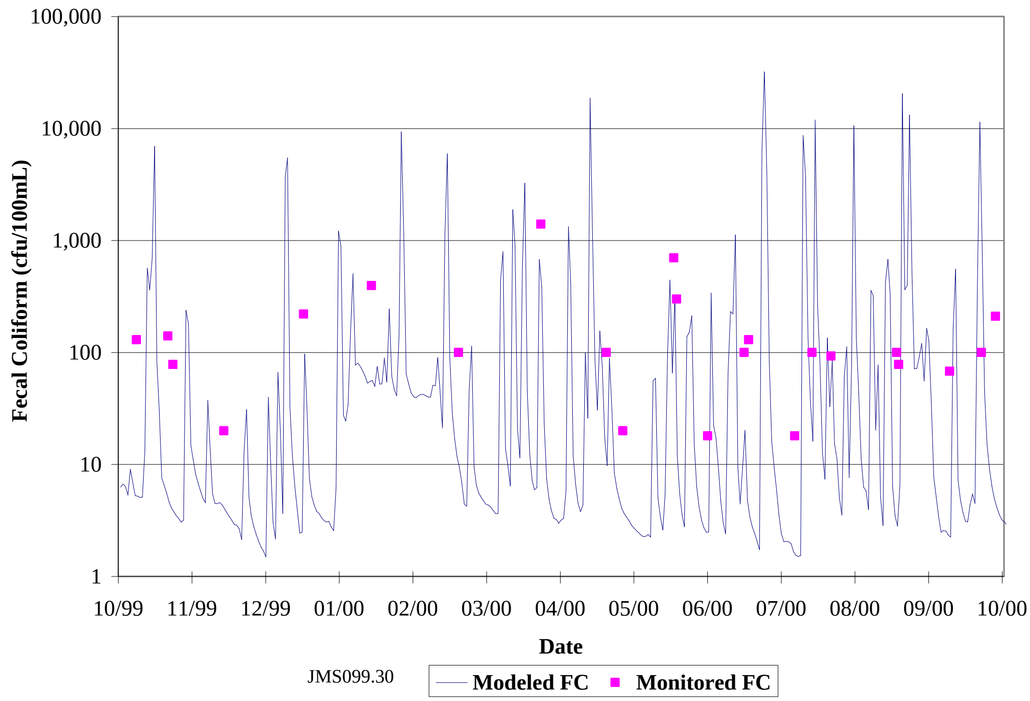

Figure 4.41 Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS099.30 in subwatershed 13 in the James River tidal impairment.

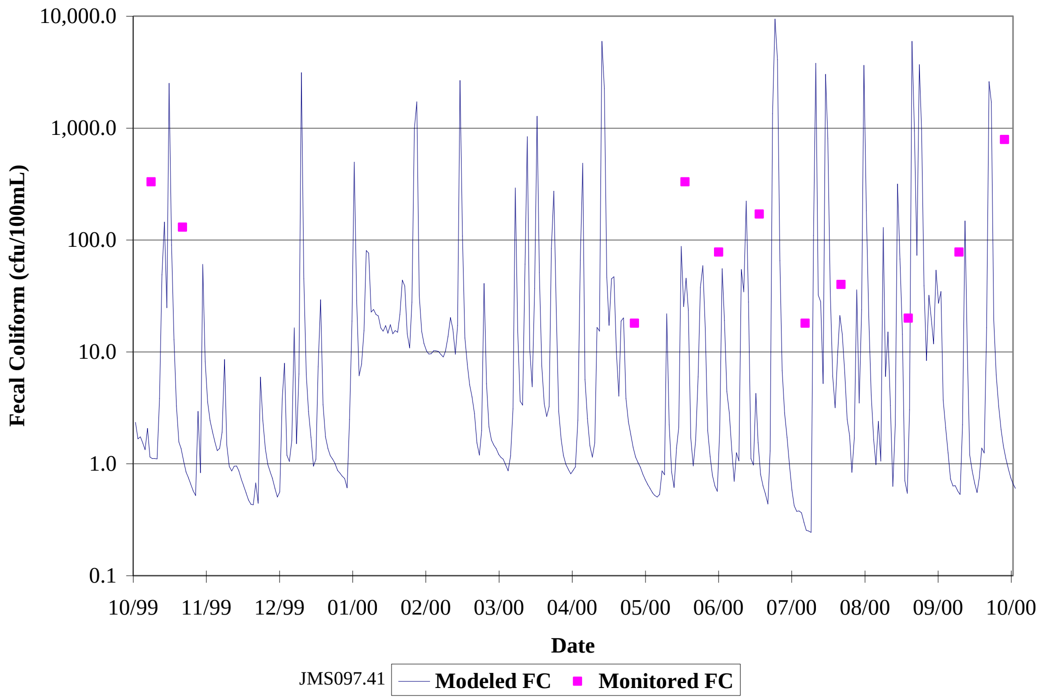

Figure 4.42 Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS097.41 in subwatershed 13 in the James River tidal impairment.

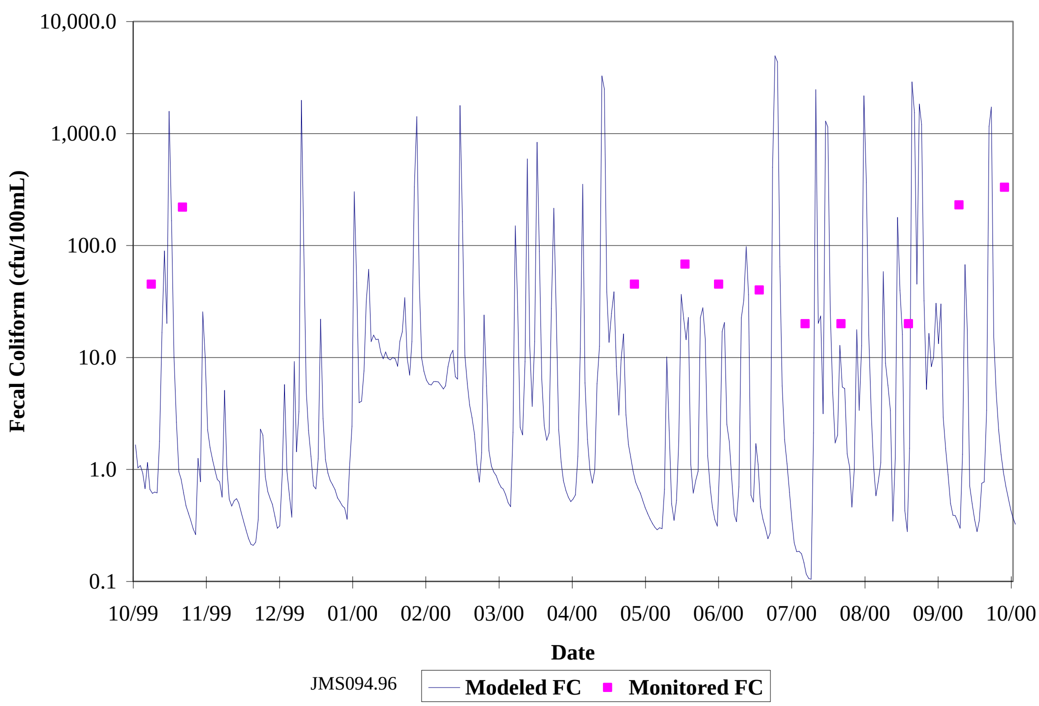

Figure 4.43 Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS094.96 in subwatershed 14 in the James River tidal impairment.

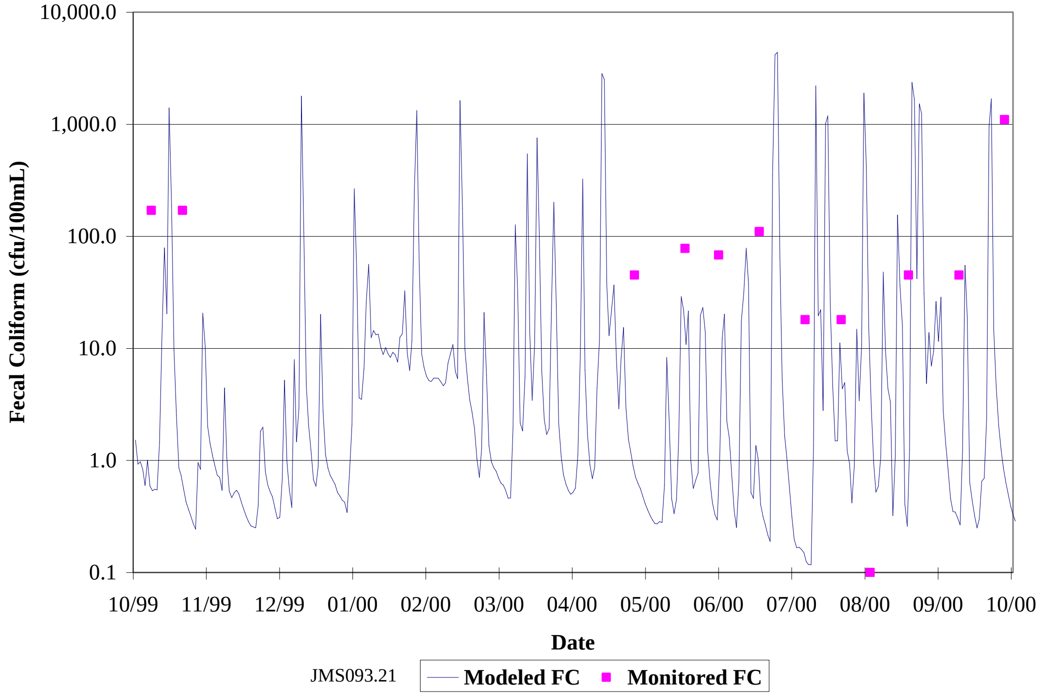

Figure 4.44 **Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS093.21 in subwatershed 14 in the James River tidal impairment.**

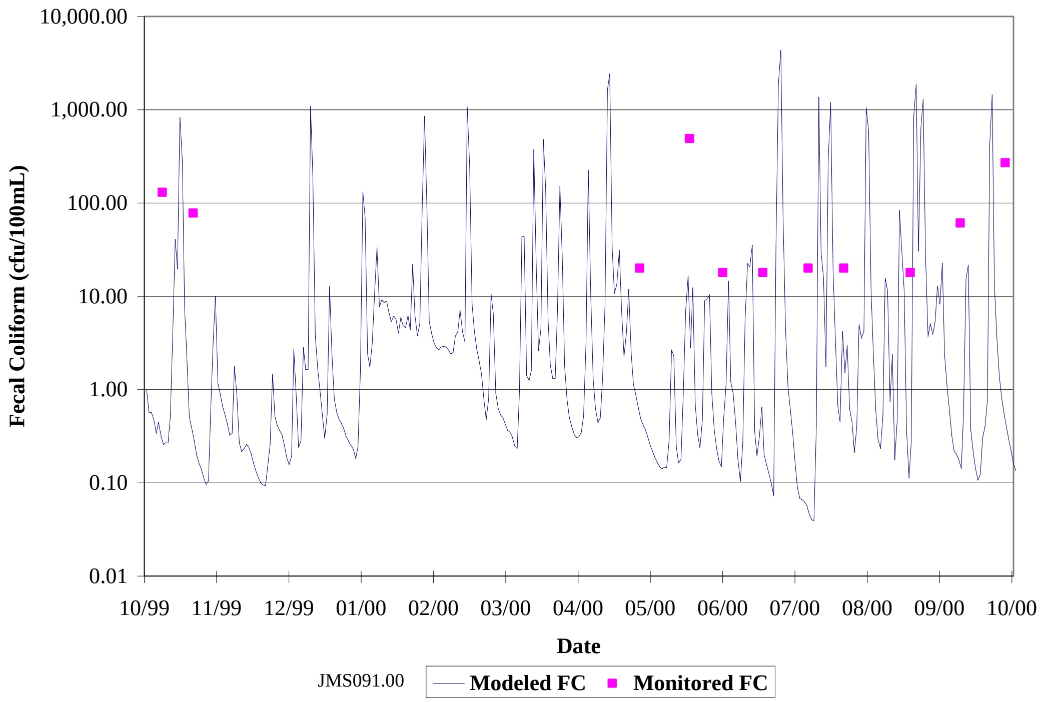

Figure 4.45 **Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS091.00 in subwatershed 14 in the James River tidal impairment.**

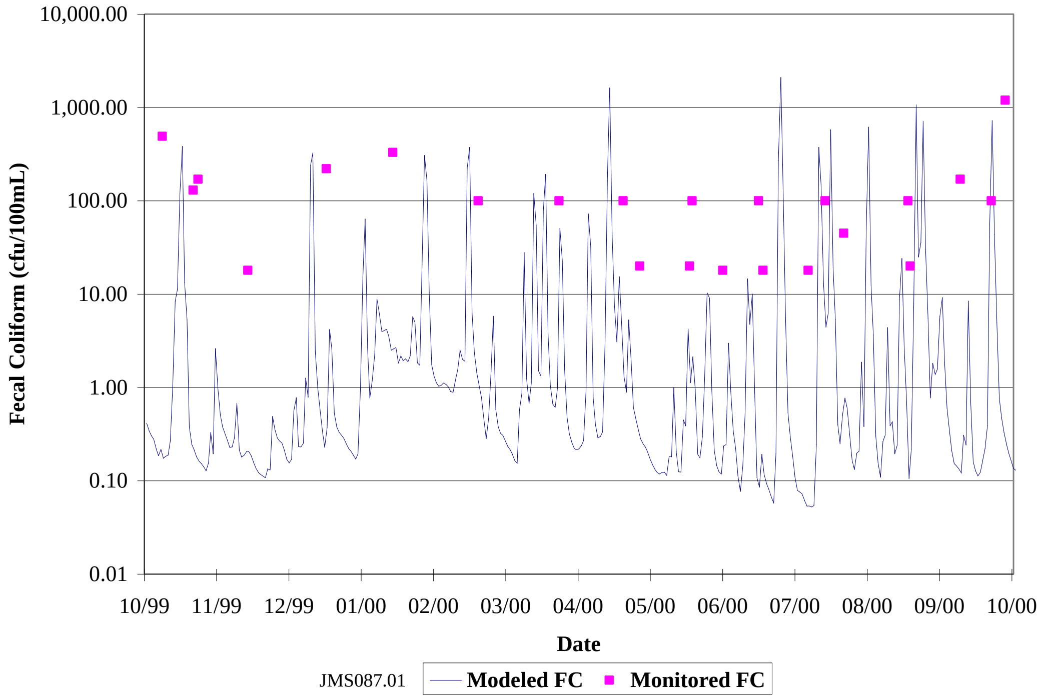

Figure 4.46 Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS087.01 in subwatershed 15 in the James River tidal impairment.

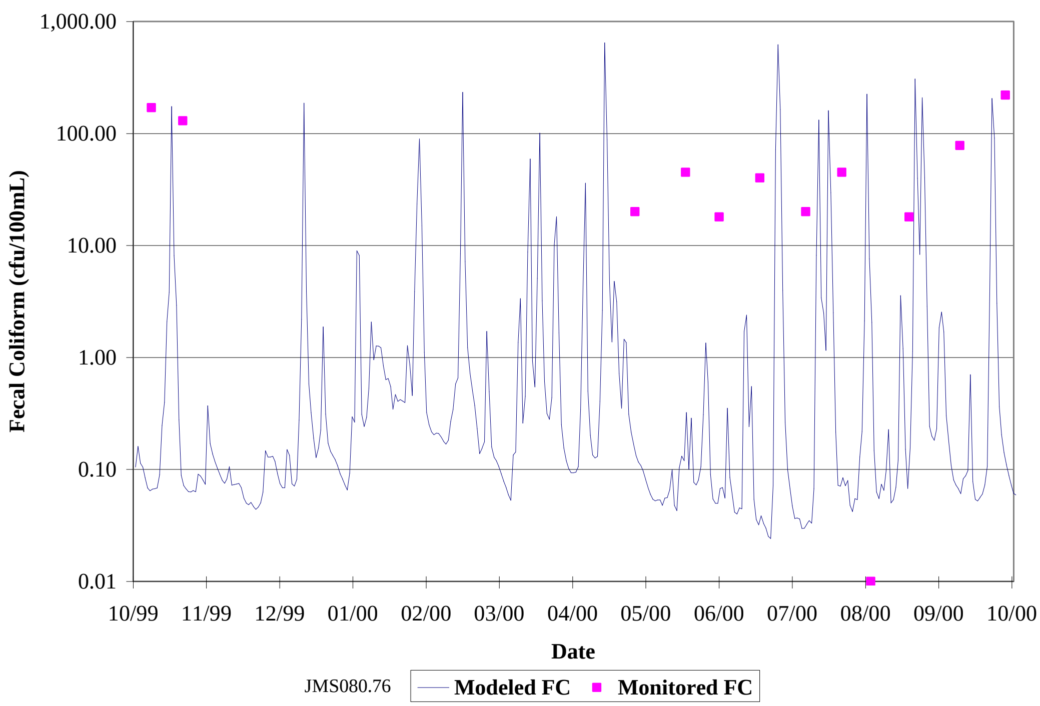

Figure 4.47 Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS080.76 in subwatershed 15 in the James River tidal impairment.

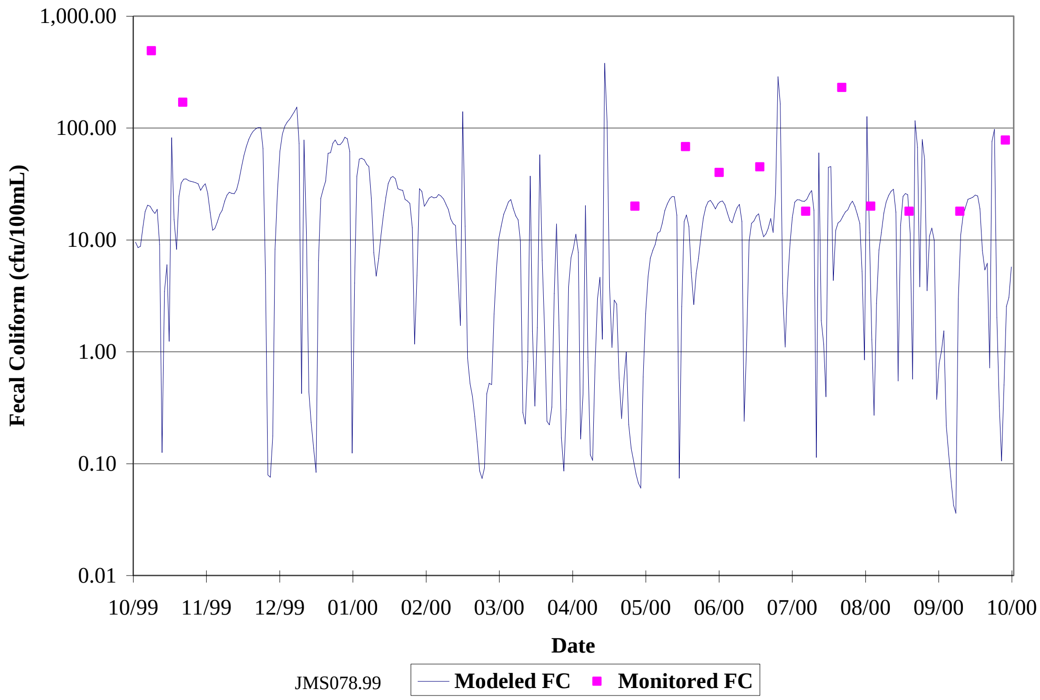

Figure 4.48 Fecal coliform quality calibration results for 10/6/1999 to 10/5/2000 for VADEQ station 2-JMS078.99in subwatershed 15 in the James River tidal impairment.

4.8 Existing Loadings

All appropriate inputs were updated to current conditions. Figure 4.49 shows the monthly geometric mean of *E. coli* concentrations in relation to the 126-cfu/100mL standard at the outlet of the Almond Creek impairment (subwatershed 18). The remaining impaired segments follow Almond Creek with a monthly geometric mean graph in this order: Bernards Creek, Falling Creek, Gillie Creek, Goode Creek, James River (upper), James River (lower), No Name Creek, Powhite Creek, and Reedy Creek. The existing conditions are shown in Figure 4.49 through 4.58. The James River (tidal) impairment was modeled using CE-QUAL-W2. The geometric mean graph is shown as Figure 4.58.

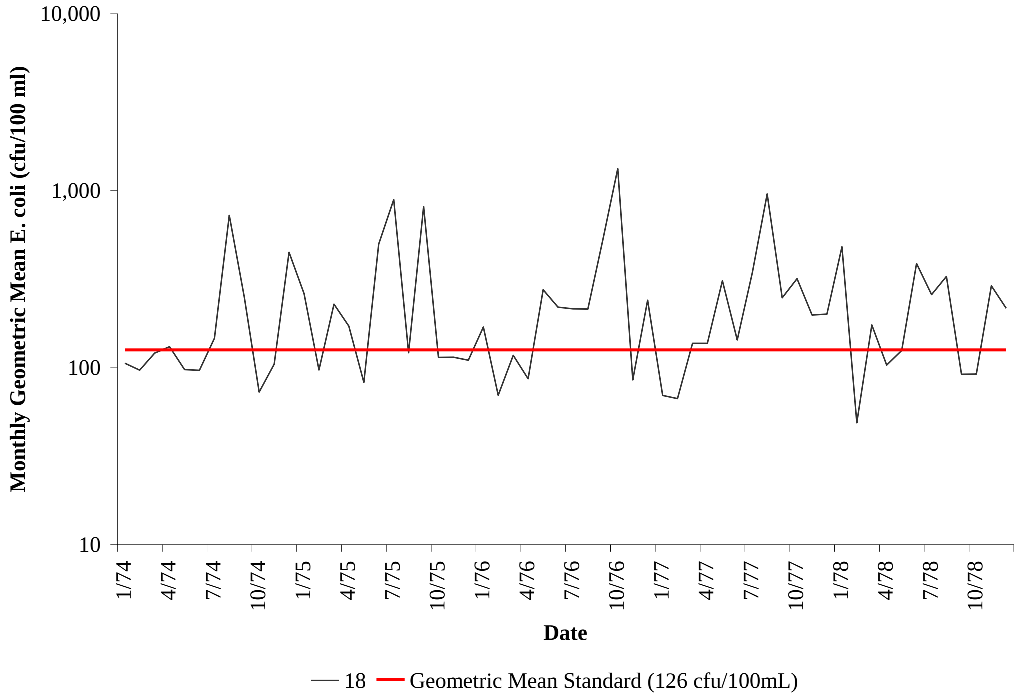

Figure 4.49 Monthly geometric mean of *E. coli* concentrations for existing conditions at the Almond Creek impairment outlet (subwatershed 18).

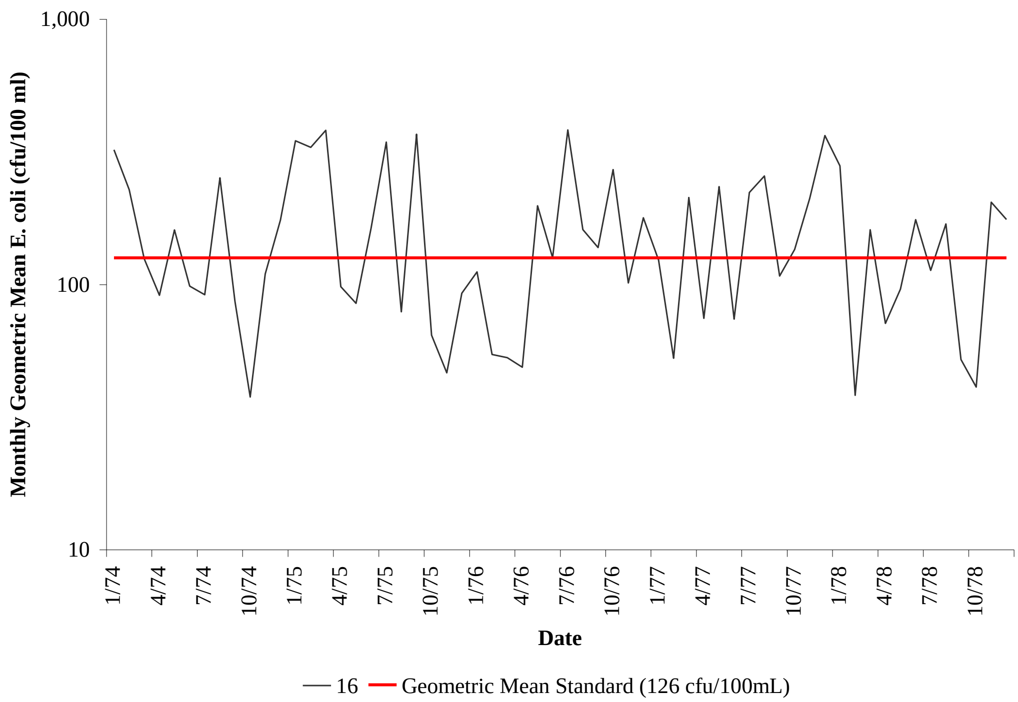

Figure 4.50 Monthly geometric mean of *E. coli* concentrations for existing conditions at the Bernards Creek impairment outlet (subwatershed 16).

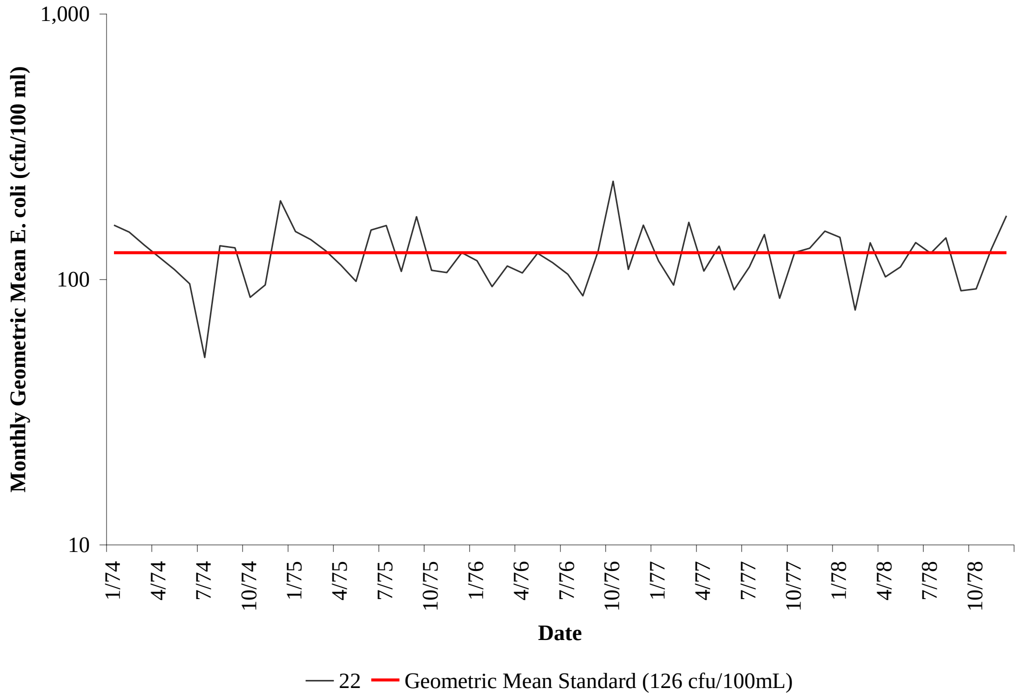

Figure 4.51 Monthly geometric mean of *E. coli* concentrations for existing conditions at the Falling Creek impairment outlet (subwatershed 22).

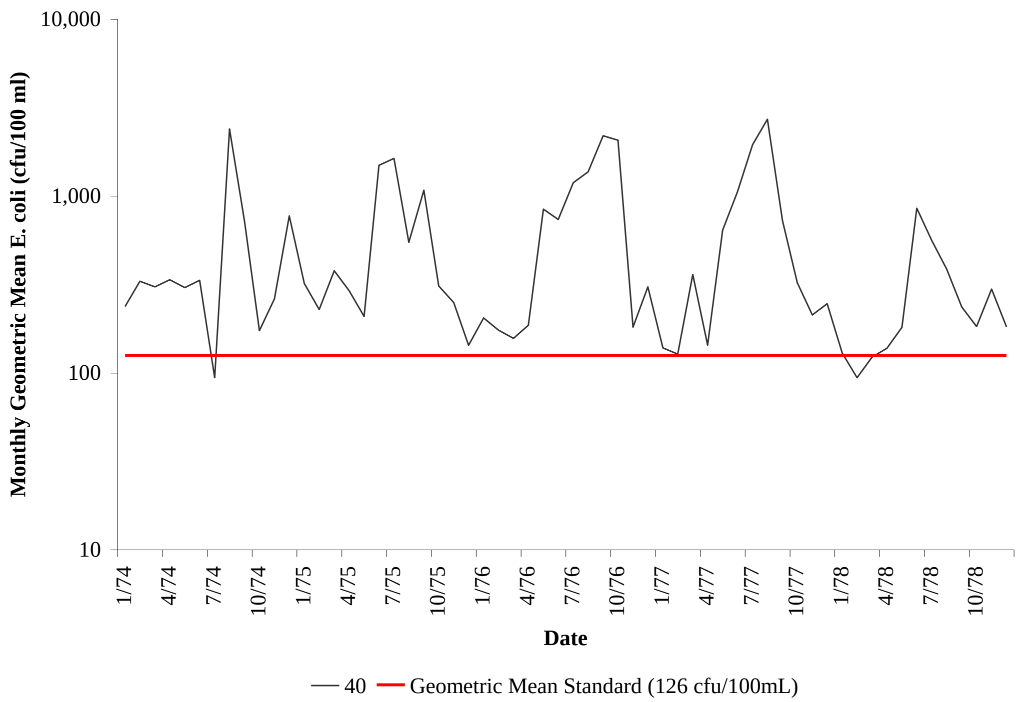

Figure 4.52 Monthly geometric mean of *E. coli* concentrations for existing conditions at the Gillie Creek impairment outlet (subwatershed 40).

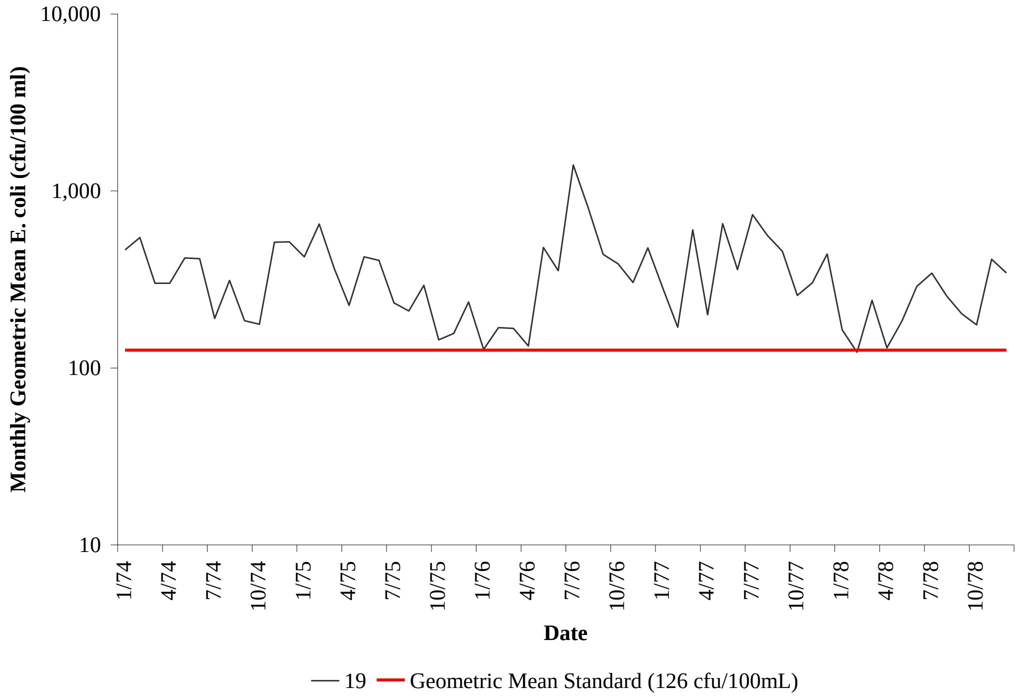

Figure 4.53 Monthly geometric mean of *E. coli* concentrations for existing conditions at the Goode Creek impairment outlet (subwatershed 19).

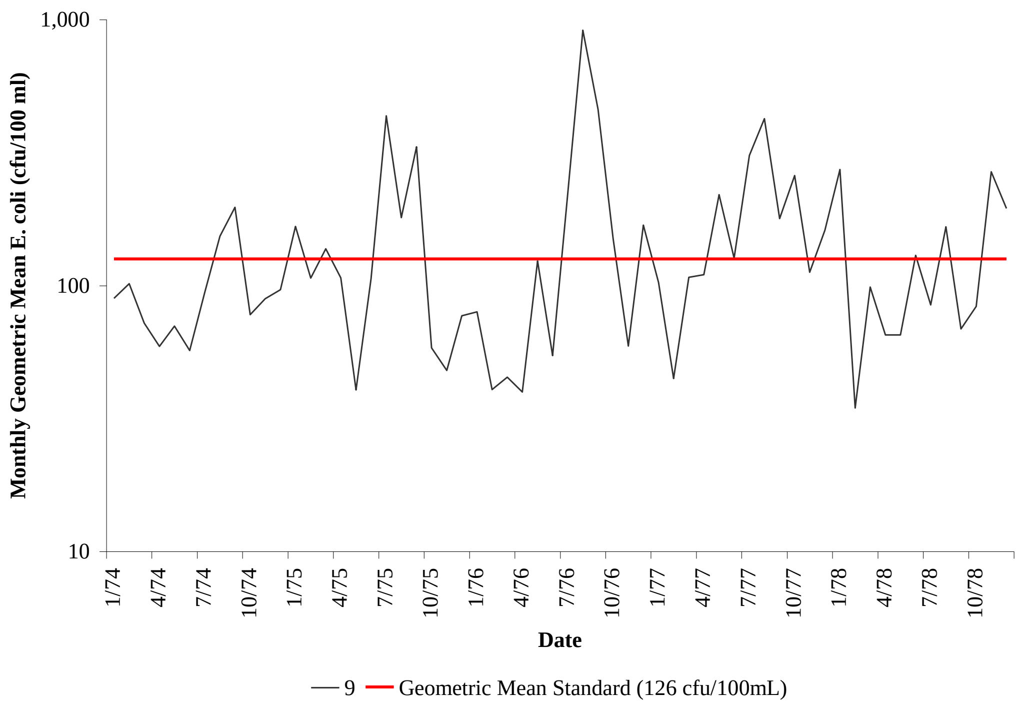

Figure 4.54 Monthly geometric mean of *E. coli* concentrations for existing conditions at the James River (lower) impairment outlet (subwatershed 9).

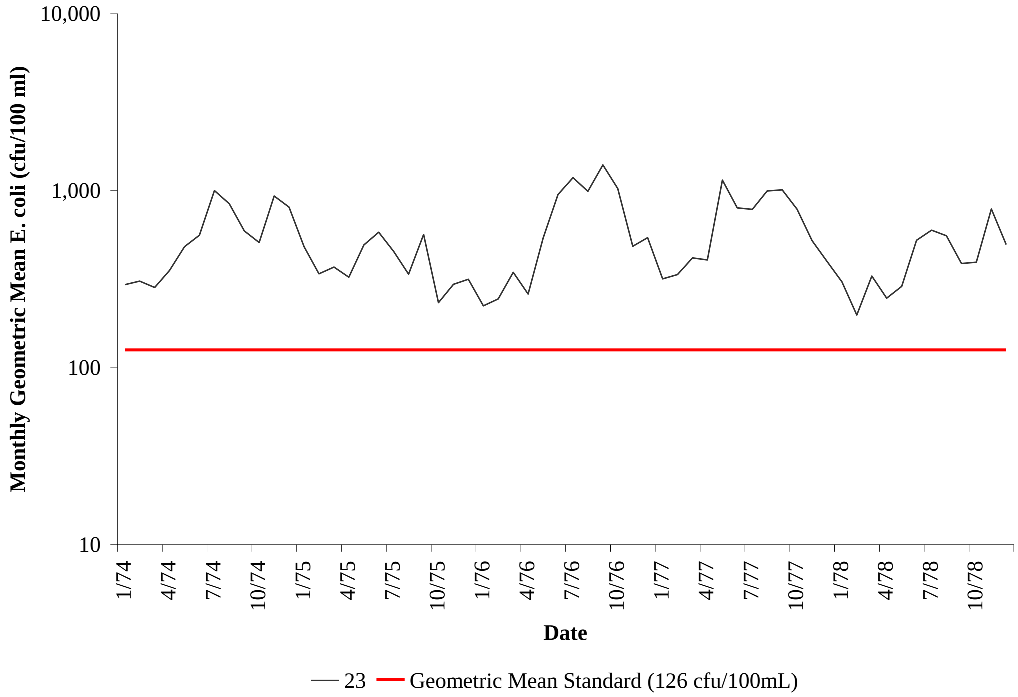

Figure 4.55 Monthly geometric mean of *E. coli* concentrations for existing conditions at the No Name Creek impairment outlet (subwatershed 23).

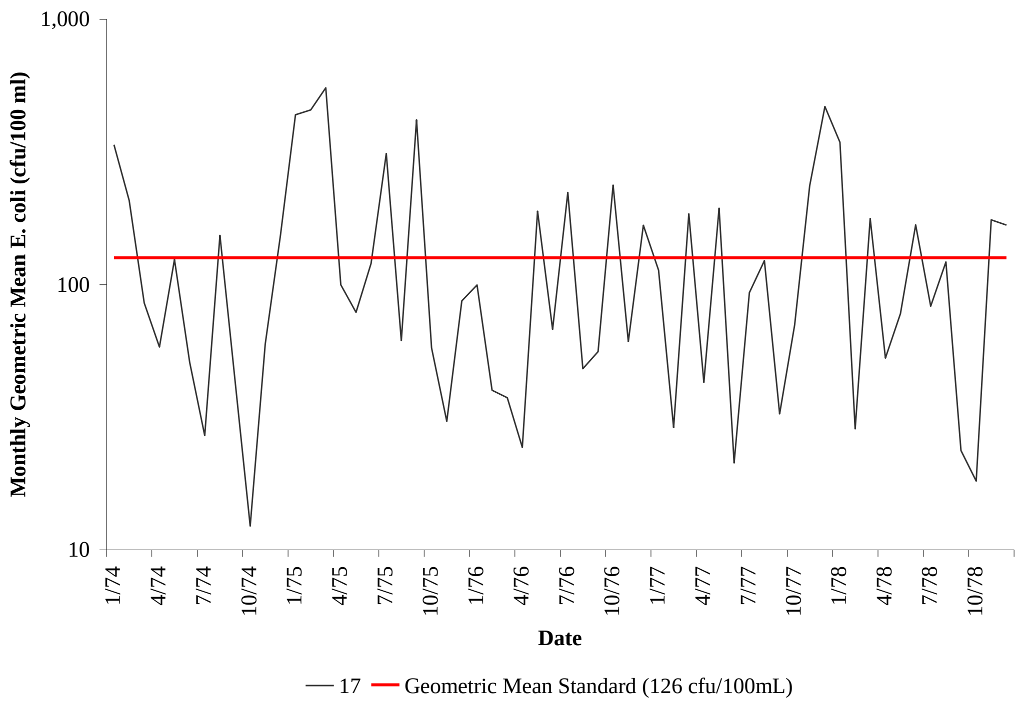

Figure 4.56 Monthly geometric mean of *E. coli* concentrations for existing conditions at the Powhite Creek impairment outlet (subwatershed 17).

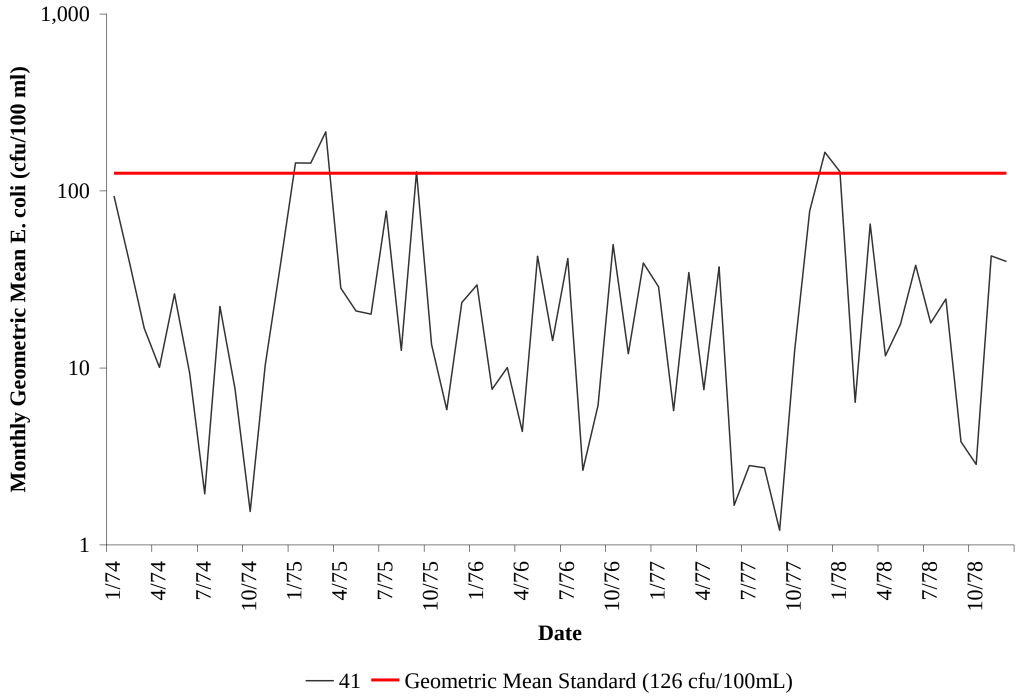

Figure 4.57 Monthly geometric mean of *E. coli* concentrations for existing conditions at the Reedy Creek impairment outlet (subwatershed 57).

Figure 4.58 Monthly geometric mean of *E. coli* concentrations for existing conditions at the James River (tidal) impairment (subwatershed 10).

5. ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, permitted sources) and load allocations (LAs, non-permitted sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g.*, accuracy of wildlife populations). The definition is typically denoted by the expression:

TMDL = WLAs + LAs + MOS

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving waterbody and still achieve water quality standards. For these impairments, the TMDLs are expressed in terms of colony forming units (or resulting concentration).

Allocation scenarios were modeled using the modified SWMM, HSPF, and CE-QUAL-W2 models. The first change made to existing conditions was adjusting the flood tides (incoming) from the James River to subwatershed 15 so that the bacteria from the tides alone did not result in water quality standards violations. In parallel to this, the incoming bacteria concentration from the upstream James River was also set to the water quality standard. Scenarios were created by reducing direct and land-based bacteria until the water quality standard was attained. The TMDLs developed for the impairments in the James River – City of Richmond study area were based on the *E. coli* riverine Virginia State standard. As detailed in Section 2.1, the VADEQ riverine primary contact recreational use *E. coli* standards state that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 ml.

According to the guidelines put forth by the VADEQ (VADEQ, 2003) for modeling bacteria with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* through the use of the following equation (developed from a data set containing 493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc}) \qquad \textit{E. coli}$$

where C_{ec} is the concentration of *E. coli* in cfu/100 mL and C_{fc} is the concentration of fecal coliform in cfu/100 mL.

Pollutant concentrations were modeled over the entire duration of a representative modeling period, and pollutant loads were adjusted until the standard was met. The development of the allocation scenario was an iterative process that required numerous runs, with each followed by an assessment of source reduction against the applicable water quality standard.

5.1 Margin of Safety (MOS)

In order to account for uncertainty in modeled output, a Margin of Safety (MOS) was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. A MOS can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of an MOS in the development of a bacteria TMDL is to ensure that the modeled loads do not underestimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of these TMDLs. By adopting an implicit MOS in estimating the loads in the watershed, it is ensured that the recommended reductions will in fact succeed in meeting the water quality standard. Examples of the implicit MOS used in the development of these TMDLs are:

- The flood tides (incoming) from the James River and the incoming bacteria concentration from the upstream James River was set to the water quality standard,
- Allocating permitted point sources at the maximum allowable fecal coliform concentration, and
- Selecting a modeling period that represented the critical hydrologic conditions in the watershed.

5.2 Waste Load Allocations (WLAs)

There are currently seven Municipal Separate Storm Sewer System (MS4) permits in the James River – City of Richmond study area that contribute bacteria to surface waters: the Defense Supply Center - Richmond (VAR040001), City of Richmond (VAR040005), Chesterfield County (VA0088609), VDOT (VAR040115), Henrico County DPW (VA0088607), John Tyler Community College (VAR040110), and Hunter Holmes

McGuire VA Hospital (VAR040116). For this report, it was assumed that all impervious land within the boundaries of these permits drains to an MS4 outfall. All *E. coli* from these areas was allocated to the MS4s in the appropriate TMDL tables. Table 5.1 shows the areas used to calculate the MS4 bacteria loads in the WLA for each impairment.

The VDOT MS4 permit coverage combines discharge from state maintained highways in the City of Richmond, Chesterfield County, and Henrico County. In most cases, MS4 areas are overlapping or intertwined and there is currently no standardized methodology for disaggregating the MS4 loads to assign individual Waste Load Allocations. EPA, DEQ and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDL.

The bacteria loads from CSOs were calculated using the modeled output from the City of Richmond's SWMM model developed for their permit requirements. The daily bacteria concentrations were multiplied by flow and the proper conversions, then averaged over one year to become loads of bacteria (cfu/year).

The WLA load for each impairment also includes a load set aside for the future growth of the human population. This factor allows for growth of new permits and the expansion of existing permits. All permitted discharges must discharge at or below the current water quality standard level; therefore, these expansions will not cause violations of the standard in-stream. The future growth load was calculated as either 1% of the final TMDL load or five times the load from wastewater treatment facilities (WWTF), except in Reedy Creek. Future growth in Reedy Creek was calculated as half the straight pipe load because 1% of the TMDL was too large. If a higher load is required for future permits, a 1% reduction from the low and medium intensity residential (LMIR) land use would allow a future growth load of 1% of the TMDL for Reedy Creek.

Table 5.1 Impervious land areas used to calculate the James River – City of Richmond area MS4 WLAs.

Impairment	Total Drainage (acres)	Impervious Land Area Within MS4 Areas (acres)					
		Defense Supply Center Richmond (VAR040001)	City of Richmond (VAR040005)/ Virginia VDOT (VAR040115)	Chesterfield County (VA0088609) / Virginia VDOT (VAR040115)	Henrico County DPW (VA0088607) / Virginia VDOT (VAR040115)	John Tyler Community College (VAR040110)	Hunter Holmes McGuire VA Hospital (VAR040116)
Almond Creek	3,342	0	21	0	386	0	0
Bernards Creek	10,932	0	0	435	0	0	0
Falling Creek	38,943	21	671	5,087	0	0	0
Gillie Creek	11,233	0	148	0	1,361	0	0
Goode Creek	4,137	0	907	0	0	0	79
James River (lower)	137,110	0	1,422	1,575	2,787	0	0
James River (tidal)	289,470	172	3,611	10,117	5,216	19	0
No Name Creek	1,100	77	0	204	0	0	0
Powhite Creek	7,387	0	287	840	0	0	0
Reedy Creek	3,108	0	472	21	0	0	0

5.3 Load Allocations (LAs)

Load allocations to nonpoint sources are divided into land-based loadings from land uses (nonpoint source, NPS) and directly applied loads in the stream (*e.g.*, livestock, wildlife). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads had their most significant impact during high-flow conditions, while direct deposition NPS had their most significant impact on low flow concentrations. The BST results confirmed the presence of human, livestock, pet, and wildlife contamination in all impairments. Nonpoint source load reductions were performed by land use, as opposed to reducing sources, as it is considered that the majority of NPS BMPs will be implemented by land use. Reductions on agricultural land uses (pasture and cropland) include reductions required for land applied livestock wastes.

5.4 Final Total Maximum Daily Loads (TMDLs)

Allocation scenarios were run sequentially, beginning with headwater impairments, and then continuing with downstream impairments until all impairments were allocated to 0% exceedances of all applicable standards. The first table in each of the following sections represents a small portion of the scenarios developed to determine the TMDLs. The first five scenarios were run for all impairments simultaneously; subsequent runs were made after upstream impairments were allocated. Scenario 1 in each table describes a baseline scenario that corresponds to the existing conditions in the watershed.

Reduction scenarios exploring the role of anthropogenic sources in standard violations were explored first to determine the feasibility of meeting the standard without wildlife reductions. In each table, Scenario 2 eliminated direct human sources (straight pipes, non-permitted sewer overflows, leaking sewer lines, and illicit cross-connections of residential wastes to the stormwater collection system). Scenario 3 shows the impact of reducing direct livestock and direct human sources. Since part of the TMDL development is the identification of phased implementation strategies, a typical management scenario was explored as well. Scenario 4 in each table contains reductions of 50% in all anthropogenic (human, livestock, and pet) land-based loads, 100% reduction in un-permitted sewer overflows and straight pipes, a 90% reduction in direct livestock deposition, and a 0% reduction in wildlife direct and land-based loading to the stream. Scenario 5 attempts to determine the impact of non-anthropogenic sources (wildlife), by exploring 100% reductions in all anthropogenic land-based and direct loads. In most cases, the model predicts that the water quality standard will not be met without reductions in wildlife loads. Further scenarios in each table explore a range of management scenarios, leading to the final allocation scenario that contains the predicted reductions needed to meet 0% exceedance of all applicable water quality standards.

For impaired stream segments that are impacted by CSOs, extra scenarios are included that show the impacts of these sources during wet weather and the treatment of dry weather flows by the Richmond WWTP. These scenarios are existing conditions (including improvements made to the treatment and structures to date), Alternative E, or Alternative E with further reductions. Alternative E refers to the preferred implementation of the City of Richmond's Phase III CSO Control Plan (Greeley and Hanson, 2006 and Appendix E, Figure E.1).

The graphs in the following sections depict the existing and allocated monthly geometric mean in-stream bacteria concentrations.

The second table in the following sections shows the existing and allocated fecal coliform land-based and direct loads that are input into the HSPF model. The third table shows the final in-stream allocated loads for the appropriate bacteria species. These values are output from the HSPF model and incorporate in-stream die-off, tidal mixing, and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The values in the second and third tables are the results of different modeling processes and it is not appropriate to directly compare values between the tables. The final table is an estimation of the in-stream daily load of bacteria.

The tables and graphs in the following sections all depict values at the corresponding impairment outlet. The impairment outlet is the mouth of the impaired segment as the segments are described in Section 1.1. It is the point at which the impaired stream flows out of the most downstream subwatershed. The impairment outlets for the impaired segments within the James River – City of Richmond are at the mouths of the subwatersheds in the "Outlet" column of Table 4.1.

5.4.1 Almond Creek

Table 5.2 shows allocation scenarios used to determine the final TMDL for Almond Creek. Because Virginia's standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational (swimming) use standard (126 cfu/100mL geometric mean). The existing condition, Scenario 1, shows the violation percentage with no reductions. Although the existing conditions had violations, Scenario 2 (eliminating non-permitted direct human inputs) showed dramatic improvement. Scenario 3 showed that eliminating direct livestock would slightly benefit water quality. A typical management scenario, Scenario 4, slightly improved water quality. This scenario showed improvement, but the standard was still not met. Scenario 5 shows 100% reductions to all anthropogenic sources; however, exceedances persisted. This scenario shows that reductions to wildlife loads or CSO loads must be made. The first 5 scenarios are explained in more detail in Section 5.4.

Scenario 6 has a 52% reduction in the CSO bacteria load with fewer reductions needed to agricultural and low and medium intensity residential (LMIR) nonpoint source loads. The standard was met with this scenario. Therefore, the final TMDL was developed using Scenario 6 with a 91% reduction from direct livestock loads, a 85% reduction from residential land-based loads, and 100% correction of straight pipes and non-permitted sewer overflows, and a 52% reduction in the CSO bacteria load beyond the reductions from Alternative E (Greeley and Hanson, 2006 and Appendix E, Figure E.1).

Scenario 7 had a 18% reduction in the CSO bacteria load with fewer reductions needed to agricultural and low intensity residential (LMIR) nonpoint source loads. Scenario 7 meets a geometric mean of 206 cfu/100mL. This scenario may be used as a first target, or Stage I, goal during the implementation of best management practices (BMPs).

Table 5.2 Allocation scenarios for reducing current bacteria loads in Almond Creek (subwatershed 18).

	Percent Reductions to Existing Bacteria Loads							
		Wildlife Land Based		**Agricultural Land Based**	**Human Direct**	**Human and Pet Land Based**	**City of Richmond CSO Program Project Plan**	**VADEQ *E. coli* Standard percent violations**
Scenario	**Wildlife Direct**	**Barren, Commercial, Forest, HIR, Wetlands**	**Livestock Direct**	**Cropland, Pasture, LAX**	**Straight Pipes**	**LMIR**	**Scenario**	**>126 GM**
1	0	0	0	0	0	0	Existing	60.00
2	0	0	0	0	100	0	Existing	15.00
3	0	0	100	0	100	0	Existing	11.67
4	0	0	90	50	100	50	Existing	10.00
5	0	0	100	100	100	100	Existing	6.67
6[1]	0	0	91	0	100	85	Alternative E and a 52% reduction	0.00
7[2]	0	0	0	0	100	78	Alternative E and an 18% reduction	NA

[1]Final TMDL Scenario
[2]Meets a GM of 206 cfu/100mL; possible Stage I scenario

Figure 5.1 shows the existing and allocated monthly geometric mean *E. coli* concentrations from Almond Creek impairment outlet. This graph shows existing conditions in black, with allocated conditions overlaid in blue.

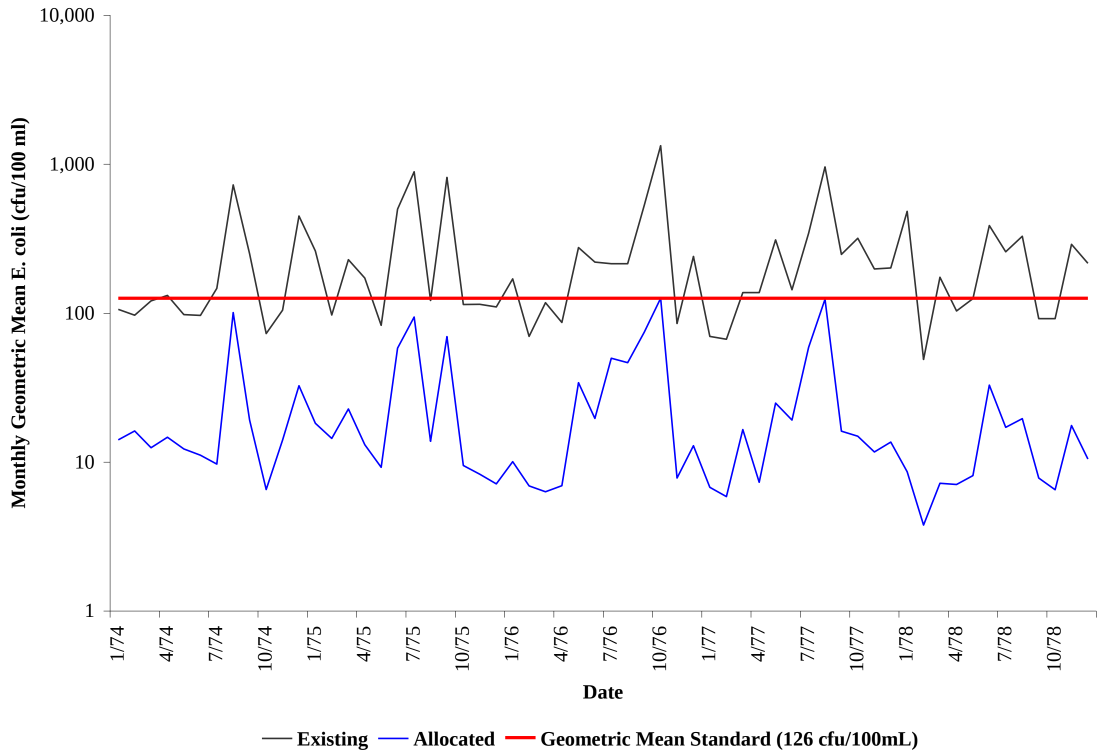

Figure 5.1 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 18, Almond Creek impairment outlet.

Table 5.3 contains estimates of existing and allocated in-stream *E. coli* loads at the Almond Creek impairment outlet reported as average annual cfu per year. The estimates in Table 5.3 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126-cfu/100mL geometric mean standard are given in the final column.

In Appendix C, Tables C.1 through C.4 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.3 Estimated existing and allocated *E. coli* in-stream loads in the Almond Creek impairment.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Barren	2.02E+10	2.02E+10	0%
	Commercial	3.56E+10	3.56E+10	0%
	Cropland	5.33E+09	5.33E+09	0%
	Forest	3.06E+10	3.06E+10	0%
	Livestock Access	0.00E+00	0.00E+00	0%
	Low and Medium Density Residential	1.53E+13	2.29E+12	85%
	Open Space	4.00E+11	4.00E+11	0%
	Pasture	2.19E+11	2.19E+11	0%
	Wetland	1.33E+09	1.33E+09	0%
Direct				
	Human	1.82E+12	0.00E+00	100%
	Livestock	5.90E+11	5.31E+10	91%
	Wildlife	4.62E+11	4.62E+11	0%
	Permitted Sources	1.74E+09	1.74E+09	0%
	Future Growth	0.00E+00	6.67E+10	NA
CSOs	CSO Loads	6.42E+12	3.08E+12	52%
Total Loads		**2.53E+13**	**6.67E+12**	**73.6%**

Table 5.4 shows the average annual TMDL, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet existing water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The City of Richmond, Henrico County, and VDOT currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the Almond Creek drainage area. In most cases, MS4 areas are overlapping or intertwined and there is currently no standardized methodology for disaggregating the MS4 loads to assign individual Waste Load Allocations. EPA, DEQ and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDL. To account for future

growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.4 Final average annual cumulative in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Almond Creek impairment.

Impairment	WLA	LA	MOS	TMDL
Almond Creek	**4.39E+12**	**2.28E+12**		**6.67E+12**
VAG404029 [1]	*1.74E+09*		*Implicit*	
MS4 City of Richmond *MS4 VDOT* [2]	*6.44E+10*			
MS4 Henrico County *MS4 VDOT* [2]	*1.18E+12*			
VA0063177: CSOs [3]	*3.08E+12*			
Future Load [4]	*6.67E+10*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] The WLA associated with the combined sewer system will be addressed through the performance standards for the facilities in the approved Long Term Control Plan (LTCP). If WQSs are not attained after the completion of CSO LTCP as determined by post-construction monitoring, additional steps may be required per EPA CSO Policy at IV.B.2.g.
[4] The WLA reflects an allocation for potential future permits issued for bacteria control.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load, as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for Almond Creek are shown in Table 5.5.

Table 5.5 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Almond Creek impairment.

Impairment	WLA	LA	MOS	TMDL[2]
Almond Creek	**1.21E+10**	**4.57E+11**	*Implicit*	**4.69E+11**
VAG404029 [1]	*4.77E+06*			
MS4 City of Richmond *MS4 VDOT* [3]	*1.77E+08*			
MS4 Henrico County *MS4 VDOT* [3]	*3.25E+09*			
VA0063177: CSOs [4]	*8.45E+09*			
Future Load [5]	*1.83E+08*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.
[3] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[4] The WLA associated with the combined sewer system will be addressed through the performance standards for the facilities in the approved Long Term Control Plan (LTCP). If WQSs are not attained after the completion of CSO LTCP as determined by post-construction monitoring, additional steps may be required per EPA CSO Policy at IV.B.2.g.
[5] The WLA reflects an allocation for potential future permits issued for bacteria control.

5.4.2 Bernards Creek

Table 5.6 shows allocation scenarios used to determine the final TMDL for Bernards Creek. Because Virginia's standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational (swimming) use standard (126 cfu/100mL geometric mean). The existing condition, Scenario 1, shows the violation percentage with no reductions. Although the existing conditions had violations, Scenario 2 (eliminating non-permitted direct human inputs) showed dramatic improvement. Scenario 3 showed that eliminating direct livestock would slightly benefit water quality. A typical management scenario, Scenario 4, slightly improved water quality. This scenario showed improvement, but the standard was still not met. Scenario 5 shows 100% reductions to all anthropogenic sources;

however, exceedances persisted. This scenario shows that reductions to wildlife loads must be made. The first 5 scenarios are explained in more detail in Section 5.4.

Scenario 6 has a 37% reduction in the land-based wildlife bacteria load with a 99% reduction to agricultural and low and medium intensity residential (LMIR) nonpoint source loads. The standard was still not met with this scenario. Scenario 7 has a 38% reduction in the land-based wildlife bacteria load, a 99% reduction to direct livestock loads, a 93% reduction to land–based agricultural loads, a 96% reduction to LMIR loads, and 100% reduction to direct human loads. This scenario met the standard. Therefore, the final TMDL was developed using Scenario 7.

Scenario 8 meets a geometric mean of 206 cfu/100mL. This scenario may be used as a first target, or Stage I, goal during the implementation of best management practices (BMPs).

Table 5.6 Allocation scenarios for reducing current bacteria loads in Bernards Creek (subwatershed 16).

	Percent Reductions to Existing Bacteria Loads						
		Wildlife Land Based		**Agricultural Land Based**	**Human Direct**	**Human and Pet Land Based**	**VADEQ *E. coli* Standard percent violations**
Scenario	**Wildlife Direct**	**Barren, Commercial, Forest, HIR, Wetlands**	**Livestock Direct**	**Cropland, Pasture, LAX**	**Straight Pipes**	**LMIR**	**>126 GM**
1	0	0	0	0	0	0	51.67
2	0	0	0	0	100	0	30.00
3	0	0	100	0	100	0	21.67
4	0	0	90	50	100	50	16.67
5	0	0	100	100	100	100	10.00
6	0	37	100	99	100	99	1.67
7[1]	0	38	99	93	100	96	0.00
8[2]	0	0	99	48	100	71	NA

[1]Final TMDL Scenario
[2]Meets a GM of 206 cfu/100mL; possible Stage I scenario

Figure 5.2 shows the existing and allocated monthly geometric mean *E. coli* concentrations from Bernards Creek impairment outlet. This graph shows existing conditions in black, with allocated conditions overlaid in blue.

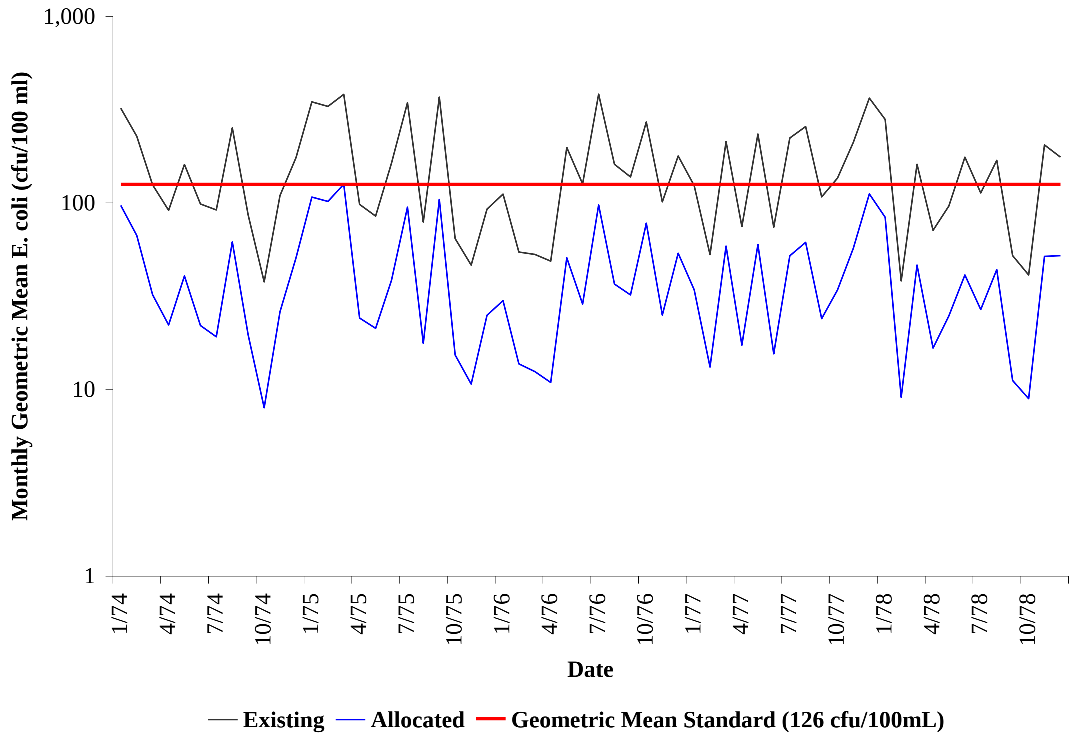

Figure 5.2 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 16, Bernards Creek impairment outlet.

Table 5.7 contains estimates of existing and allocated in-stream *E. coli* loads at the Bernards Creek impairment outlet reported as average annual cfu per year. The estimates in Table 5.7 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126-cfu/100mL geometric mean standard are given in the final column.

In Appendix C, Tables C.5 through C.8 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.7 Estimated existing and allocated *E. coli* in-stream loads in the Bernards Creek impairment.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Barren	0.00E+00	0.00E+00	0%
Commercial	3.64E+07	2.26E+07	38%
Cropland	1.77E+12	1.24E+11	93%
Forest	1.45E+14	8.99E+13	38%
Livestock Access	4.25E+09	2.97E+08	93%
Low and Medium Density Residential	6.10E+13	2.44E+12	96%
Open Space	1.12E+14	6.94E+13	38%
Pasture	4.11E+13	2.87E+12	93%
Wetland	9.32E+11	5.78E+11	38%
Direct			
Human	1.88E+12	0.00E+00	100%
Livestock	5.88E+11	5.88E+09	99%
Wildlife	3.48E+05	3.48E+05	0%
Permitted Sources	0.00E+00	0.00E+00	0%
Future Growth	0.00E+00	1.67E+12	NA
Total Loads	**3.64E+14**	**1.67E+14**	**54.1%**

Table 5.8 shows the average annual TMDL, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet the existing water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.8 Final average annual cumulative in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Bernards Creek impairment.

Impairment	WLA	LA	MOS	TMDL
Bernards Creek	**1.67E+12**	**1.65E+14**	*Implicit*	**1.67E+14**
Future Load [1]	*1.67E+12*			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for Bernards Creek are shown in Table 5.9.

Table 5.9 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Bernards Creek impairment.

Impairment	WLA	LA	MOS	TMDL[2]
Bernards Creek	**4.58E+09**	**1.01E+12**	*Implicit*	**1.01E+12**
Future Load [1]	4.58E+09			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.

5.4.3 Falling Creek

Table 5.10 shows allocation scenarios used to determine the final TMDL for Falling Creek. Because Virginia's standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational (swimming) use standard (126 cfu/100mL geometric mean). The existing condition, Scenario 1, shows the violation percentage with no reductions. Although the existing conditions had violations, Scenario 2 (eliminating non-permitted direct human inputs) showed dramatic improvement. Scenario 3 showed that eliminating direct livestock would not benefit water quality. A typical management scenario, Scenario 4, shows no standard violations. Scenario 5 shows 100% reductions to all anthropogenic sources, showing that reductions to wildlife loads are not required. The first 5 scenarios are explained in more detail in Section 5.4.

Scenario 6 has a 13% reduction to low and medium intensity residential (LMIR) nonpoint source loads and a 100% correction of straight pipes and non-permitted sewer overflows. This scenario met the standard. Therefore, the final TMDL was developed using Scenario 6.

Scenario 2 meets a geometric mean of 206 cfu/100mL. This scenario may be used as a first target, or Stage I, goal during the implementation of best management practices (BMPs).

Table 5.10 Allocation scenarios for reducing current bacteria loads in Falling Creek (subwatershed 22).

Percent Reductions to Existing Bacteria Loads							
		Wildlife Land Based		**Agricultural Land Based**	**Human Direct**	**Human and Pet Land Based**	**VADEQ *E. coli* Standard percent violations**
Scenario	**Wildlife Direct**	**Barren, Commercial, Forest, HIR, Wetlands**	**Livestock Direct**	**Cropland, Pasture, LAX**	**Straight Pipes**	**LMIR**	**>126 GM**
1	0	0	0	0	0	0	46.67
2[2]	0	0	0	0	100	0	1.67
3	0	0	100	0	100	0	1.67
4	0	0	90	50	100	50	0.00
5	0	0	100	100	100	100	0.00
6[1]	0	0	0	0	100	13	0.00

[1]Final TMDL Scenario
[2]Meets a GM of 206 cfu/100mL; possible Stage I scenario

Figure 5.3 shows the existing and allocated monthly geometric mean *E. coli* concentrations from Falling Creek impairment outlet. This graph shows existing conditions in black, with allocated conditions overlaid in blue.

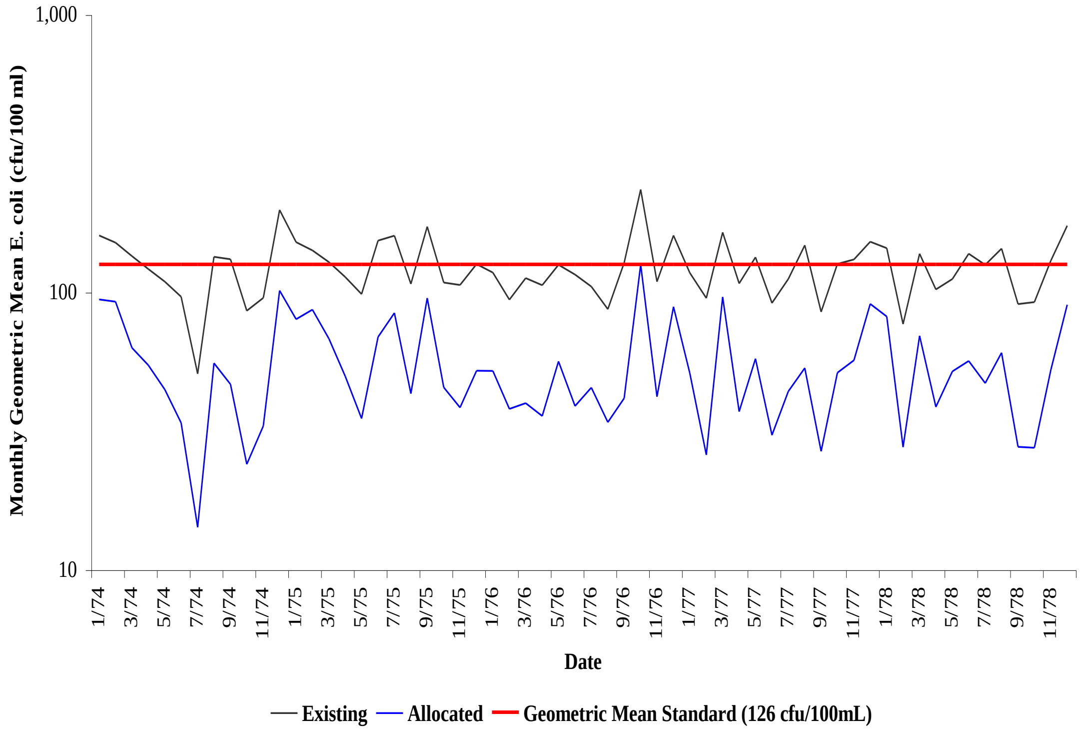

Figure 5.3 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 22, Falling Creek impairment outlet.

Table 5.11 contains estimates of existing and allocated in-stream *E. coli* loads at the Falling Creek impairment outlet reported as average annual cfu per year. The estimates in Table 5.11 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126-cfu/100mL geometric mean standard are given in the final column.

In Appendix C, Tables C.9 through C.12 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.11 Estimated existing and allocated *E. coli* in-stream loads in the Falling Creek impairment.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Barren	1.55E+09	1.55E+09	0%
Commercial	5.97E+10	5.97E+10	0%
Cropland	7.37E+08	7.37E+08	0%
Forest	3.41E+12	3.41E+12	0%
Livestock Access	2.73E+08	2.73E+08	0%
Low and Medium Density Residential	7.47E+13	6.50E+13	13%
Open Space	8.64E+12	8.64E+12	0%
Pasture	2.08E+11	2.08E+11	0%
Wetland	7.19E+09	7.19E+09	0%
Direct			
Human	1.95E+13	0.00E+00	100%
Livestock	2.64E+12	2.64E+12	0%
Wildlife	1.47E+13	1.47E+13	0%
Permitted Sources	1.74E+09	1.74E+09	0%
Future Growth	0.00E+00	9.56E+11	NA
Total Loads	**1.24E+14**	**9.56E+13**	**22.8%**

Table 5.12 shows the average annual TMDL, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet the existing water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The City of Richmond, Chesterfield County, the Defense Supply Center, and VDOT currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the Falling Creek drainage area. There is currently no standardized methodology acceptable to all stakeholders for disaggregating the VDOT MS4 load from that of the municipality's MS4

load for assigning waste load allocations, due to the continuity of the drainage systems. Therefore, each municipality MS4 permit and its adjacent portion of the VDOT MS4 permit were assigned an aggregated load in the TMDL. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.12 Final average annual cumulative in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Falling Creek impairment.

Impairment	WLA	LA	MOS	TMDL
Falling Creek	**1.64E+13**	**7.92E+13**		**9.56E+13**
VAG404238 [1]	*1.74E+09*		*Implicit*	
MS4 Defense Supply Center – Richmond [2]	*5.60E+10*			
MS4 City of Richmond *MS4 VDOT* } [2]	*1.79E+12*			
MS4 Chesterfield County *MS4 VDOT* } [2]	*1.36E+13*			
Future Load [3]	*9.56E+11*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] The WLA reflects an allocation for potential future permits issued for bacteria control.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for Falling Creek are shown in Table 5.13.

Table 5.13 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Falling Creek impairment.

Impairment	WLA	LA	MOS	TMDL[2]
Falling Creek	**4.48E+10**	**6.43E+12**	Implicit	**6.47E+12**
VAG404238 [1]	*4.77E+06*			
MS4 Defense Supply Center – Richmond [3]	*1.53E+08*			
MS4 City of Richmond *MS4 VDOT* } [3]	*4.90E+09*			
MS4 Chesterfield County *MS4 VDOT* } [3]	*3.72E+10*			
Future Load [4]	*2.62E+09*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.
[3] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[4] The WLA reflects an allocation for potential future permits issued for bacteria control.

5.4.4 Gillie Creek

Table 5.14 shows allocation scenarios used to determine the final TMDL for Gillie Creek. Because Virginia's standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational (swimming) use standard (126 cfu/100mL geometric mean). The existing condition, Scenario 1, shows the violation percentage with no reductions. Scenario 2 (eliminating non-permitted direct human inputs) showed improvement. Scenario 3 showed that eliminating direct livestock would not benefit water quality. A typical management scenario, Scenario 4, slightly improved water quality. This scenario showed improvement, but the standard was still not met. Scenario 5 shows 100% reductions to all anthropogenic sources except CSO loads and exceedances persisted. This scenario shows that reductions to wildlife loads or CSO loads must be made. The first 5 scenarios are explained in more detail in Section 5.4.

Scenario 6a incorporates the City of Richmond's Long Term Control Plan (LTCP) Alternative E with no further reductions (Alternative E is explained in Section 5.4 and Greeley and Hanson, 2006 and Appendix E, Figure E.1). This scenario decreases the violation percentage by 1.67%. Scenario 6 shows Alternative E with a 94% reduction from low and medium intensity residential (LMIR) nonpoint source loads and a 100% correction of straight pipes and non-permitted sewer overflows. This scenario does not meet the standard, but is closer with a 15% violation rate.

Scenario 7 incorporates the City of Richmond's Long Term Control Plan Alternative E with an additional 95% reduction in bacteria from the CSOs, as well as a 94% reduction from low and medium intensity residential (LMIR) nonpoint source loads and a 100% correction of straight pipes and non-permitted sewer overflows. This scenario meets the primary contact standard and was used in TMDL calculations (Alternative E is explained in Section 5.4 and Greeley and Hanson, 2006 and Appendix E, Figure E.1).

Scenario 8 meets a geometric mean of 206 cfu/100mL. Scenario 8 includes Alternative E and an additional 91% reduction in bacteria from the CSOs, a 92% reduction from LMIR nonpoint source loads, and a 100% correction of straight pipes and non-permitted sewer overflows.

In Scenario 9, Gillie Creek was divided into upstream (9a) and downstream (9b) segments. This is due to the fact that the downstream 1.7 miles is a limited-access concrete channel (Figure 5.4), while the upstream section is a natural stream. The upstream section, which includes subwatersheds 40 and 71, and CSO #031, was allocated to meet the primary contact recreational use standard (126 cfu/100mL geometric mean). The upstream segment needs a 96% reduction from LMIR nonpoint source loads, a 100% correction of straight pipes and non-permitted sewer overflows, and Alternative E to meet the 126 cfu/100mL geometric mean primary contact standard. The remaining subwatersheds and CSO contributions (#004, #024, #025, #026, #028, #031, and #039) were allocated to the secondary contact recreational use standard (a geometric mean of 630 cfu/100mL) while keeping the upstream allocation the same. This lower section of Gillie Creek has limited access and a low appeal for swimming. The downstream segment needs a 97% reduction from LMIR nonpoint source loads, a 100% correction of straight pipes and non-permitted sewer overflows, and Alternative E with an additional 73% reduction in bacteria from the CSOs to meet the 630 cfu/100mL geometric mean secondary contact standard. Thus scenario 9a and 9b in Table 5.14 were presented here to examine what the reductions would be if the upper section (9a) met the primary contact recreational use standard (126 cfu/100mL geometric mean) and the lower section (9b) met the secondary contact recreational use standard (630 cfu/100mL geometric mean).

The implementation of the scenario 9a/9b alternative makes logical sense, as the lower Gillie Creek section is a concrete channel with limited access. Swimming is uncommon, as it is not aesthetically pleasing, with existing signage to restrict access. Also the design, location of channel, and fencing make the channel difficult to access. A portion of the implementation could be further limiting access to this section of the stream, including more descriptive signage to discourage swimming. Using the scenario 9a/9b combination for Gillie Creek during implementation could provide reasonable assurance that Virginia's standards can be met in a way that is both logical and economical for all stakeholders involved.

Figure 5.4 Gillie Creek looking upstream from Railroad Bridge above Government Road; Concrete Trapezoid; May 1, 2009.

Two scenarios were evaluated with both environmental and economic benefits in mind. Scenario 10 in Table 5.14 shows the violation percentage if 5MG (million gallons) of storage is implemented for the Gillie Creek CSOs. Comparing Scenario 10 to Scenario 6a (implementing only Alternative E) shows that the additional 5MG of storage would reduce violations by approximately 28.33%. The addition of the 5MG storage reduces the number of days with overflows during the five year modeling time periods from 297 days to 9 days. Further investigation, Scenario 11, shows that with the same reductions to human direct sources (100%) and LMIR sources (94%) as those needed to meet the standard in Scenario 7, plus the additional 5MG of storage for Gillie Creek CSOs, the percent violation rate is 3.33%. This provides a 91.67% reduction in percent violations from the existing conditions (Scenario 1); and a 90% reduction in percent violations from implementing Alternative E only (Scenario 6a). Scenarios 10 or 11 could be used during implementation plan development as optional stages for Gillie Creek .

The City of Richmond has completed preliminary cost estimates for the implementation of the scenarios that call for reductions beyond Alternative E. The City has estimated that to implement 29.2MG of storage resulting in the needed 95% reduction in CSO bacteria load (Scenario 7) would cost taxpayers $300 million dollars. Similarly to implement the Scenario 9a/9b combination would cost $230 million dollars to construct 22.4MG of storage to obtain the needed 73% reduction in CSO bacteria load.

Table 5.14 Allocation scenarios for reducing current bacteria loads in Gillie Creek (subwatersheds 40, 63-68, 71, 79).

		Percent Reductions to Existing Bacteria Loads						
		Wildlife Land Based		**Agricultural Land Based**	**Human Direct**	**Human and Pet Land Based**	**City of Richmond CSO Program Project Plan**	**VADEQ *E. coli* Standard percent violations**
Scenario	**Wildlife Direct**	**Barren, Commercial, Forest, HIR, Wetlands**	**Livestock Direct**	**Cropland, Pasture, LAX**	**Straight Pipes**	**LMIR**	**Scenario**	**>126 GM**
1	0	0	0	0	0	0	Existing	95.00
2	0	0	0	0	100	0	Existing	60.00
3	0	0	100	0	100	0	Existing	60.00
4	0	0	90	50	100	50	Existing	55.00
5	0	0	100	100	100	100	Existing	38.33
6a	0	0	0	0	0	0	Alternative E	93.33
6	0	0	0	0	100	94	Alternative E	15.00
7[1]	0	0	0	0	100	94	Alternative E and a 95% reduction	0.00
8[2]	0	0	0	0	100	92	Alternative E and a 91% reduction	0.0 >206 GM
9a[3]	0	0	0	0	100	96	Alternative E	0.00
9b[4]	0	0	0	0	100	97	Alternative E and a 73% reduction	0.0 >630 GM
10	0	0	0	0	0	0	Alternative E and 5MG storage	65.0
11	0	0	0	0	100	94	Alternative E and 5MG storage	3.33

[1]Final TMDL Scenario; [2]Meets a GM of 206 cfu/100mL; [3]Upstream Gillie Creek meets a GM of 126 cfu/100mL; primary contract recreational use standard; [4]Downstream Gillie Creek meets a GM of 630 cfu/100mL; secondary contract recreational use standard

Considering the City of Richmond's estimated high cost for containing/treating overflows to meet water quality standards during extreme storm events in the Gillie Creek trapezoid ($230 - $300 million), there is a concern that this expenditure does not appear to be practical or cost-effective when compared with the marginal benefit of the swimming use, based on the City's cost estimates. A temporary use removal in the Gillie Creek trapezoid during extreme storm overflows is a prudent option to consider in this impairment.

In situations similar to Gillie Creek, EPA has allowed states to use TMDL reports as technical support documents in the UAA process to make use modifications when necessary. Some states have followed EPA's suggestion by integrating TMDLs with the use modification and implementation planning processes. Following is an excerpt of Virginia's Water Quality Standard 9 VAC 25-260-10.I:, which guides the Board regarding the removal of designated uses:

I. The board may not remove designated uses if:

1. They are existing uses, unless a use requiring more stringent criteria is added; or

2. Such uses will be attained by implementing effluent limits required under §§ 301(b)(1)(A) and (B) and 306 of the Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control.

The path forward for the Gillie Creek trapezoid concrete channel portion of the TMDL, the TMDL Implementation Plan (IP), and a possible Use Attainability Analysis (UAA) may include the following:

- <u>Complete TMDL:</u> The TMDL allocations shown in Tables 5-16 and 5-17 (below) are prepared to meet the current geometric mean water quality standard criterion. However, attainment of the designated use will be further evaluated in the TMDL IP phase and a UAA may be conducted. The modeling results for the scenarios presented in Table 5-14 may be used as part of the technical support in the development of a UAA.

- Prepare TMDL IP: As part of the TMDL IP, additional data will be collected that may support the development of a UAA. Items that should be further evaluated in the TMDL IP include:

  - Evaluation of the James River at the confluence with Gillie Creek: Section 131.10(b) of the CWA indicates that a UAA shall take into "consideration downstream waters and ensuring that WQS provide for the attainment and maintenance of downstream standards". TMDL modeling results have indicated that no additional reductions to CSOs in Gillie Creek beyond Alternative E are required to meet the water quality standards in the James River at all subwatershed outlets. Preliminary modeling results of the impact of a Gillie Creek bacterial plume on the James River at Rocketts Landing indicate that no additional reductions to CSOs in Gillie Creek beyond Alternative E may be required to meet the WQS in the James River. Also, DEQ is collecting additional monitoring data to verify the extent of the bacterial plume and the influence of Gillie Creek on the James River. All of which will be documented in the TMDL IP.

  - Warning System: In addition to the existing signs discouraging primary and secondary body contact recreation, a real time alert signal is an important component of a possible temporary use removal, which should be detailed in the TMDL IP.

- Use Attainability Analysis (UAA, should one be necessary): The TMDL and the IP would serve as technical support documents in the development of a UAA. A UAA would need to be prepared to address all the regulatory provisions identified in 40 CFR 131.10. EPA's Water Quality Standards Handbook includes guidance on the basic steps for determining how and when a designated use may be removed/modified (EPA, 1983). The steps would be fully documented in a UAA.

Figure 5.5 shows the existing and allocated monthly geometric mean *E. coli* concentrations from Gillie Creek impairment outlet. This graph shows existing conditions in black, with allocated conditions overlaid in blue.

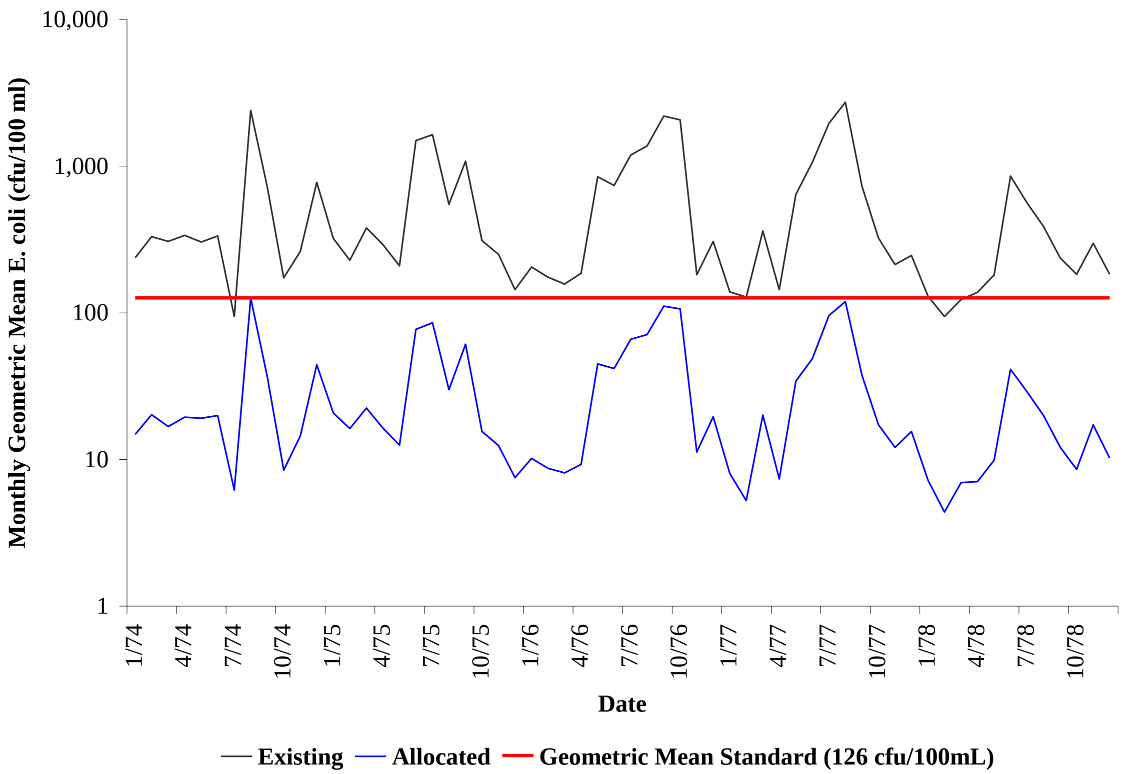

Figure 5.5 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 40, Gillie Creek impairment outlet.

Table 5.15 contains estimates of existing and allocated in-stream *E. coli* loads at the Gillie Creek impairment outlet reported as average annual cfu per year. The estimates in Table 5.15 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126-cfu/100mL geometric mean standard are given in the final column.

In Appendix C, Tables C.13 through C.16 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.15 Estimated existing and allocated *E. coli* in-stream loads in the Gillie Creek impairment.

	Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Barren	1.26E+10	1.26E+10	0%
	Commercial	3.57E+10	3.57E+10	0%
	Cropland	5.11E+09	5.11E+09	0%
	Forest	7.78E+10	7.78E+10	0%
	Livestock Access	0.00E+00	0.00E+00	0%
	Low and Medium Density Residential	3.35E+13	2.01E+12	94%
	Open Space	8.98E+11	8.98E+11	0%
	Pasture	2.39E+11	2.39E+11	0%
	Wetland	1.45E+09	1.45E+09	0%
Direct				
	Human	7.01E+12	0.00E+00	100%
	Livestock	2.76E+11	2.76E+11	0%
	Wildlife	4.39E+11	4.39E+11	0%
	Permitted Sources	0.00E+00	0.00E+00	0%
	Future Growth	0.00E+00	6.29E+10	NA
CSOs	CSO Loads	4.46E+13	2.23E+12	95%
Total Loads		**8.71E+13**	**6.29E+12**	**92.8%**

Table 5.16 shows the average annual TMDL, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet the existing water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The City of Richmond, Henrico County, and VDOT currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the Gillie Creek drainage area. In most cases, MS4 areas are overlapping or intertwined and there is currently no standardized methodology for disaggregating the MS4 loads to assign individual Waste Load Allocations. EPA, DEQ and DCR support the aggregation of MS4 WLAs for this reason. Additionally,

aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDL. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.16 Final average annual cumulative in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Gillie Creek impairment.

Impairment	WLA	LA	MOS	TMDL
Gillie Creek	**2.93E+12**	**3.36E+12**	*Implicit*	**6.29E+12**
MS4 City of Richmond *MS4 VDOT* [1]	*6.28E+10*			
MS4 Henrico County *MS4 VDOT* [1]	*5.78E+11*			
VA0063177: CSOs [2]	*2.23E+12*			
Future Load [3]	*6.29E+10*			

[1] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[2] The WLA associated with the combined sewer system will be addressed through the performance standards for the facilities in the approved Long Term Control Plan (LTCP). If WQSs are not attained after the completion of CSO LTCP as determined by post-construction monitoring, additional steps may be required per EPA CSO Policy at IV.B.2.g.
[3] The WLA reflects an allocation for potential future permits issued for bacteria control.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for Gillie Creek are shown in Table 5.17.

Table 5.17 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Gillie Creek impairment.

Impairment	WLA[1]	LA	MOS	TMDL[2]
Gillie Creek	**8.03E+09**	**1.58E+12**		**1.59E+12**
MS4 City of Richmond *MS4 VDOT* [1]	*1.72E+08*		*Implicit*	
MS4 Henrico County *MS4 VDOT* [1]	*1.58E+09*			
VA0063177: CSOs [3]	*6.11E+09*			
Future Load [4]	*1.72E+08*			

[1] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.
[3] The WLA associated with the combined sewer system will be addressed through the performance standards for the facilities in the approved Long Term Control Plan (LTCP). If WQSs are not attained after the completion of CSO LTCP as determined by post-construction monitoring, additional steps may be required per EPA CSO Policy at IV.B.2.g.
[4] The WLA reflects an allocation for potential future permits issued for bacteria control.

5.4.5 Goode Creek

Table 5.18 shows allocation scenarios used to determine the final TMDL for Goode Creek. Because Virginia's standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational (swimming) use standard (126 cfu/100mL geometric mean). The existing condition, Scenario 1, shows the violation percentage with no reductions. Although the existing conditions had violations, Scenario 2 (eliminating non-permitted direct human inputs) showed improvement. Scenario 3 showed that eliminating direct livestock would not benefit water quality. A typical management scenario, Scenario 4, shows 47% standard violations. Scenario 5 shows 100% reductions to all anthropogenic sources, showing that reductions to wildlife loads are not required. The first 5 scenarios are explained in more detail in Section 5.4.

Scenario 6 has a 96% reduction to low and medium intensity residential (LMIR) nonpoint source loads and a 100% correction of straight pipes and non-permitted sewer overflows.

This scenario met the standard. Therefore, the final TMDL was developed using Scenario 6.

Scenario 7 meets a geometric mean of 206 cfu/100mL. This scenario may be used as a first target, or Stage I, goal during the implementation of best management practices (BMPs).

Table 5.18 Allocation scenarios for reducing current bacteria loads in Goode Creek (subwatershed 19).

	Percent Reductions to Existing Bacteria Loads						
		Wildlife Land Based		Agricultural Land Based	Human Direct	Human and Pet Land Based	VADEQ *E. coli* Standard percent violations
Scenario	Wildlife Direct	Barren, Commercial, Forest, HIR, Wetlands	Livestock Direct	Cropland, Pasture, LAX	Straight Pipes	LMIR	>126 GM
1	0	0	0	0	0	0	98.33
2	0	0	0	0	100	0	70.00
3	0	0	100	0	100	0	70.00
4	0	0	90	50	100	50	46.67
5	0	0	100	100	100	100	0.00
6[1]	0	0	0	0	100	96	0.00
7[2]	0	0	0	0	100	90	NA

[1]Final TMDL Scenario
[2]Meets a GM of 206 cfu/100mL; possible Stage I scenario

Figure 5.6 shows the existing and allocated monthly geometric mean *E. coli* concentrations from Goode Creek impairment outlet. This graph shows existing conditions in black, with allocated conditions overlaid in blue.

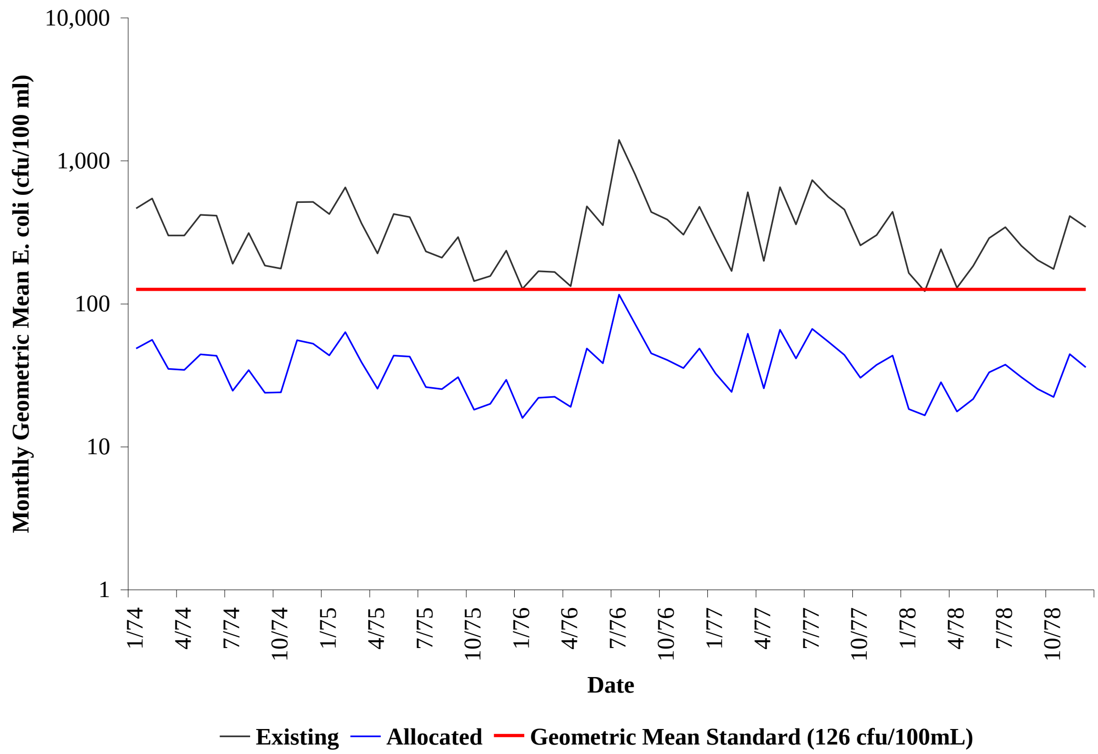

Figure 5.6 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 19, Goode Creek impairment outlet.

Table 5.19 contains estimates of existing and allocated in-stream *E. coli* loads at the Goode Creek impairment outlet reported as average annual cfu per year. The estimates in Table 5.19 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126-cfu/100mL geometric mean standard are given in the final column.

In Appendix C, Tables C.17 through C.20 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.19 Estimated existing and allocated *E. coli* in-stream loads in the Goode Creek impairment.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Barren	8.99E+09	8.99E+09	0%
Commercial	4.23E+11	4.23E+11	0%
Cropland	0.00E+00	0.00E+00	0%
Forest	1.70E+11	1.70E+11	0%
Livestock Access	0.00E+00	0.00E+00	0%
Low and Medium Density Residential	6.98E+13	2.79E+12	96%
Open Space	1.90E+12	1.90E+12	0%
Pasture	0.00E+00	0.00E+00	0%
Wetland	2.70E+09	2.70E+09	0%
Direct			
Human	1.58E+12	0.00E+00	100%
Livestock	1.68E+06	1.68E+06	0%
Wildlife	2.71E+11	2.71E+11	0%
Permitted Sources	0.00E+00	0.00E+00	0%
Future Growth	0.00E+00	5.62E+10	NA
Total Loads	**7.42E+13**	**5.62E+12**	**92.4%**

Table 5.20 shows the average annual TMDL, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet the existing water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The City of Richmond, the Hunter Holmes McGuire VA Hospital, and VDOT currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the Goode Creek drainage area. In most cases, MS4 areas are overlapping or intertwined and there is currently no standardized methodology for disaggregating the MS4 loads to assign individual Waste

Load Allocations. EPA, DEQ and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDL. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.20 Final average annual cumulative in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Goode Creek impairment.

Impairment	WLA	LA	MOS	TMDL
Goode Creek	**2.52E+12**	**3.10E+12**	*Implicit*	**5.62E+12**
MS4 City of Richmond / *MS4 VDOT* } [1, 2]	*2.27E+12*			
McGuire VA Hospital [2]	*1.98E+11*			
Future Load [3]	*5.62E+10*			

[1] The City of Richmond MS4 load has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system.
[2] For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] The WLA reflects an allocation for potential future permits issued for bacteria control.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for Goode Creek are shown in Table 5.21.

Table 5.21 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Goode Creek impairment.

Impairment		WLA	LA	MOS	TMDL[3]
Goode Creek		**7.45E+09**	**8.58E+11**	*Implicit*	**8.65E+11**
MS4 City of Richmond *MS4 VDOT*	}[1, 2]	*6.75E+09*			
McGuire VA Hospital[2]		*5.42E+08*			
Future Load[4]		*1.54E+08*			

[1] The City of Richmond MS4 load has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system.
[2] For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.
[4] The WLA reflects an allocation for potential future permits issued for bacteria control.

5.4.6 No Name Creek

Table 5.22 shows allocation scenarios used to determine the final TMDL for No Name Creek. Because Virginia's standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational (swimming) use standard (126 cfu/100mL geometric mean). The existing condition, Scenario 1, shows the violation percentage with no reductions. Although the existing conditions had 100% violations, Scenario 2 (eliminating non-permitted direct human inputs) showed dramatic improvement. Scenario 3 showed that eliminating direct livestock would not benefit water quality. A typical management scenario, Scenario 4, shows 35% standard violations. Scenario 5 shows 100% reductions to all anthropogenic sources, showing that reductions to wildlife loads are not required. The first 5 scenarios are explained in more detail in Section 5.4.

Scenario 6 has a 94% reduction to agricultural and to low and medium intensity residential (LMIR) nonpoint source loads, a 100% reduction to direct livestock loads and a 100% correction of straight pipes and non-permitted sewer overflows. This scenario has 1.67% violations of the standard. With a 0.5% more reduction to low and medium intensity residential (LMIR) nonpoint source loads and a 100% correction of straight pipes and non-permitted sewer overflows, Scenario 7 meets the standard. Therefore, the final TMDL was developed using Scenario 7.

Scenario 8 meets a geometric mean of 206 cfu/100mL. This scenario may be used as a first target, or Stage I, goal during the implementation of best management practices (BMPs).

Table 5.22 Allocation scenarios for reducing current bacteria loads in No Name Creek (subwatershed 23).

	Percent Reductions to Existing Bacteria Loads						
		Wildlife Land Based		Agricultural Land Based	Human Direct	Human and Pet Land Based	VADEQ *E. coli* Standard percent violations
Scenario	**Wildlife Direct**	**Barren, Commercial, Forest, HIR, Wetlands**	**Livestock Direct**	**Cropland, Pasture, LAX**	**Straight Pipes**	**LMIR**	**>126 GM**
1	0	0	0	0	0	0	100.00
2	0	0	0	0	100	0	56.67
3	0	0	100	0	100	0	56.67
4	0	0	90	50	100	50	35.00
5	0	0	100	100	100	100	0.00
6	0	0	100	94	100	94	1.67
7[1]	0	0	0	0	100	94.5	0
8[2]	0	0	0	0	100	87	NA

[1]Final TMDL Scenario
[2]Meets a GM of 206 cfu/100mL; possible Stage I scenario

Figure 5.7 shows the existing and allocated monthly geometric mean *E. coli* concentrations from No Name Creek impairment outlet. This graph shows existing conditions in black, with allocated conditions overlaid in blue.

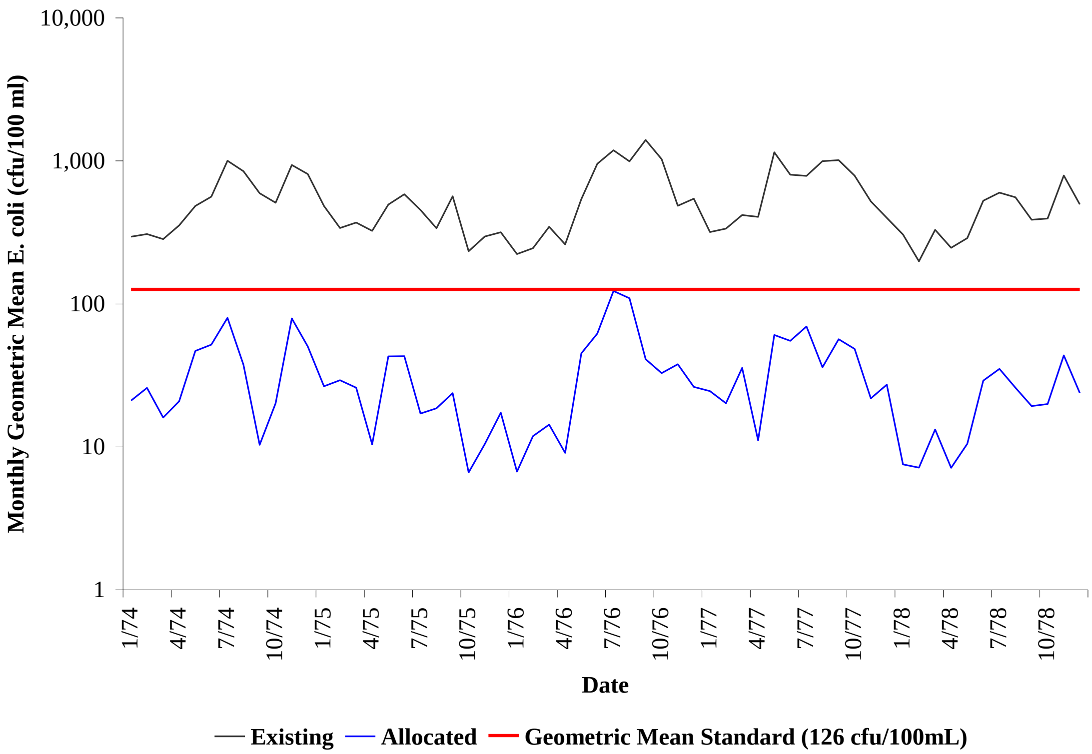

Figure 5.7 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 23, No Name Creek impairment outlet.

Table 5.23 contains estimates of existing and allocated in-stream *E. coli* loads at the No Name Creek impairment outlet reported as average annual cfu per year. The estimates in Table 5.23 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126-cfu/100mL geometric mean standard are given in the final column.

In Appendix C, Tables C.33 through C.36 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.23 Estimated existing and allocated *E. coli* in-stream loads in the No Name Creek impairment.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Barren	1.85E+09	1.85E+09	0%
Commercial	8.97E+10	8.97E+10	0%
Cropland	5.13E+10	5.13E+10	0%
Forest	3.07E+11	3.07E+11	0%
Livestock Access	0.00E+00	0.00E+00	0%
Low and Medium Density Residential	9.57E+12	5.26E+11	94.5%
Open Space	5.20E+11	5.20E+11	0%
Pasture	3.83E+10	3.83E+10	0%
Wetland	4.01E+10	4.01E+10	0%
Direct			
Human	1.45E+12	0.00E+00	100%
Livestock	4.19E+05	4.19E+05	0%
Wildlife	2.20E+10	2.20E+10	0%
Permitted Sources	0.00E+00	0.00E+00	0%
Future Growth	0.00E+00	1.61E+10	NA
Total Loads	**1.21E+13**	**1.61E+12**	**86.7%**

Table 5.24 shows the average annual TMDL, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet the existing water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The Defense Supply Center, Chesterfield County, and VDOT currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the No Name Creek drainage area. In most cases, MS4 areas are overlapping or intertwined and there is currently no standardized methodology for disaggregating the MS4 loads to assign individual Waste Load Allocations. EPA, DEQ and DCR support the aggregation of MS4 WLAs for this

reason. Additionally, aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDL. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.24 Final average annual cumulative in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the No Name Creek impairment.

Impairment	WLA	LA	MOS	TMDL
No Name Creek	**4.66E+11**	**1.15E+12**	*Implicit*	**1.61E+12**
MS4 Defense Supply Center – Richmond [1]	*1.23E+11*			
MS4 Chesterfield County *MS4 VDOT* } [1, 2]	*3.27E+11*			
Future Load [3]	*1.61E+10*			

[1] For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[2] The Chesterfield County MS4 load has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system.
[3] The WLA reflects an allocation for potential future permits issued for bacteria control.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for No Name Creek are shown in Table 5.25.

Table 5.25 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the No Name Creek impairment.

Impairment	WLA	LA	MOS	TMDL[4]
No Name Creek	**1.28E+09**	**2.32E+11**	*Implicit*	**2.33E+11**
MS4 Defense Supply Center – Richmond [1]	*3.38E+08*			
MS4 Chesterfield County / *MS4 VDOT* } [1, 2]	*8.95E+08*			
Future Load [3]	*4.42E+07*			

[1] For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[2] The Chesterfield County MS4 load has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system.
[3] The WLA reflects an allocation for potential future permits issued for bacteria control.
[4] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.

5.4.7 Powhite Creek

Table 5.26 shows allocation scenarios used to determine the final TMDL for Powhite Creek. Because Virginia's standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational (swimming) use standard (126 cfu/100mL geometric mean). The existing condition, Scenario 1, shows the violation percentage with no reductions. Although the existing conditions had violations, Scenario 2 (eliminating non-permitted direct human inputs) showed improvement. Scenario 3 showed that eliminating direct livestock would slightly benefit water quality. A typical management scenario, Scenario 4, shows 8% standard violations. Scenario 5 shows 100% reductions to all anthropogenic sources, showing that reductions to wildlife loads are not required. The first 5 scenarios are explained in more detail in Section 5.4.

Scenario 6 has an 86% reduction to low and medium intensity residential (LMIR) nonpoint source loads, a 40% reduction to direct livestock loads and a 100% correction of straight pipes and non-permitted sewer overflows and meets the standard. Therefore, the final TMDL was developed using Scenario 6.

Scenario 7 meets a geometric mean of 206 cfu/100mL. This scenario may be used as a first target, or Stage I, goal during the implementation of best management practices (BMPs).

Table 5.26 Allocation scenarios for reducing current bacteria loads in Powhite Creek (subwatershed 17).

	Percent Reductions to Existing Bacteria Loads						
		Wildlife Land Based		**Agricultural Land Based**	**Human Direct**	**Human and Pet Land Based**	**VADEQ *E. coli* Standard percent violations**
Scenario	**Wildlife Direct**	**Barren, Commercial, Forest, HIR, Wetlands**	**Livestock Direct**	**Cropland, Pasture, LAX**	**Straight Pipes**	**LMIR**	**>126 GM**
1	0	0	0	0	0	0	36.67
2	0	0	0	0	100	0	13.33
3	0	0	100	0	100	0	13.33
4	0	0	90	50	100	50	8.33
5	0	0	100	100	100	100	0.00
6[1]	0	0	40	0	100	86	0.00
7[2]	0	0	0	0	100	62	NA

[1]Final TMDL Scenario
[2]Meets a GM of 206 cfu/100mL; possible Stage I scenario

Figure 5.8 shows the existing and allocated monthly geometric mean *E. coli* concentrations from Powhite Creek impairment outlet. This graph shows existing conditions in black, with allocated conditions overlaid in blue.

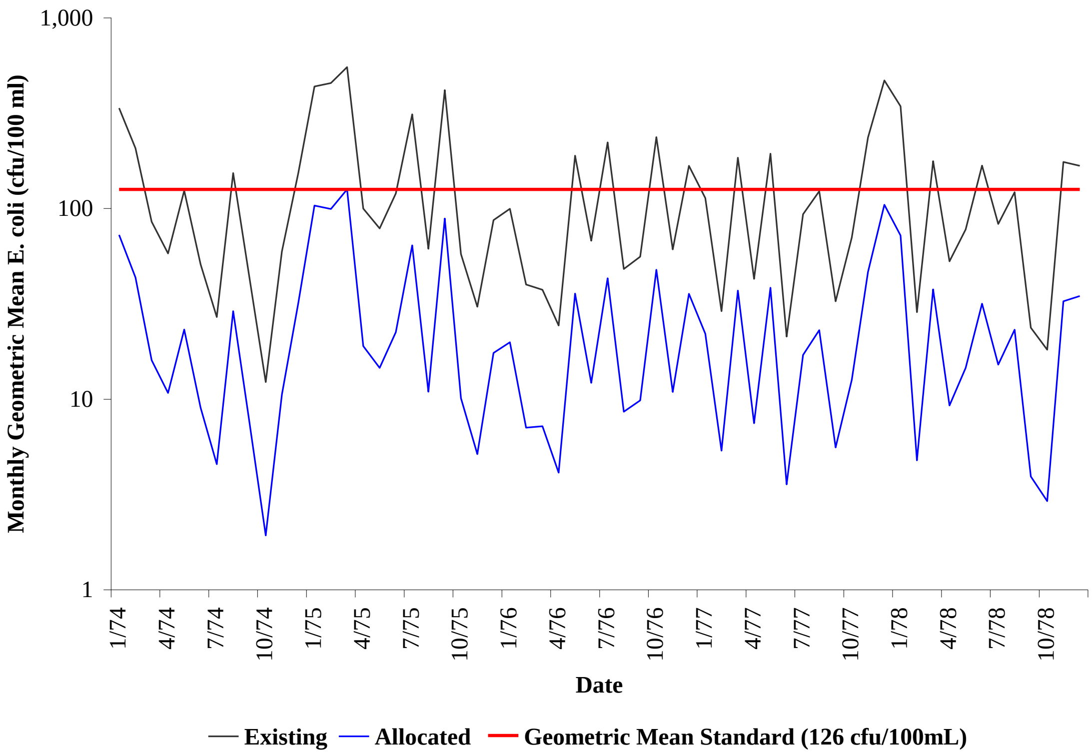

Figure 5.8 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 17, Powhite Creek impairment outlet.

Table 5.27 contains estimates of existing and allocated in-stream *E. coli* loads at the Powhite Creek impairment outlet reported as average annual cfu per year. The estimates in Table 5.27 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126-cfu/100mL geometric mean standard are given in the final column.

In Appendix C, Tables C.37 through C.40 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation. The percent reductions needed to meet zero percent violations of all applicable water quality standard are given in the final column.

Table 5.27 Estimated existing and allocated *E. coli* in-stream loads in the Powhite Creek impairment.

Source	**Total Annual Loading for Existing Run** (cfu/yr)	**Total Annual Loading for Allocation Run** (cfu/yr)	**Percent Reduction**
Land Based			
Barren	2.15E+09	2.15E+09	0%
Commercial	1.21E+10	1.21E+10	0%
Cropland	1.51E+06	1.51E+06	0%
Forest	5.95E+12	5.95E+12	0%
Livestock Access	0.00E+00	0.00E+00	0%
Low and Medium Density Residential	1.02E+15	1.42E+14	86%
Open Space	1.82E+14	1.82E+14	0%
Pasture	4.96E+10	4.96E+10	0%
Wetland	1.21E+10	1.21E+10	0%
Direct			
Human	8.83E+11	0.00E+00	100%
Livestock	3.35E+10	2.01E+10	40%
Wildlife	3.48E+05	3.48E+05	0%
Permitted Sources	1.74E+09	1.74E+09	0%
Future Growth	0.00E+00	3.34E+12	NA
Total Loads	**1.21E+15**	**3.34E+14**	**72.3%**

Table 5.28 shows the average annual TMDL, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet the existing water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.28 Final average annual cumulative in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Powhite Creek impairment.

Impairment	WLA	LA	MOS	TMDL
Powhite Creek	**3.34E+12**	**3.31E+14**	*Implicit*	**3.34E+14**
VAG404219 [1]	*1.74E+09*			
Future Load [2]	*3.34E+12*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The WLA reflects an allocation for potential future permits issued for bacteria control.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for Powhite Creek are shown in Table 5.29.

Table 5.29 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Powhite Creek impairment.

Impairment	WLA	LA	MOS	TMDL[2]
Powhite Creek	**9.15E+09**	**1.29E+12**	*Implicit*	**1.30E+12**
VAG404219 [1]	*4.77E+06*			
Future Load [3]	*9.15E+09*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.
[3] The WLA reflects an allocation for potential future permits issued for bacteria control.

5.4.8 Reedy Creek

Table 5.30 shows allocation scenarios used to determine the final TMDL for Reedy Creek. Because Virginia's standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational (swimming) use standard (126 cfu/100mL geometric mean). The existing condition, Scenario 1, shows the violation percentage with no reductions. Although the existing conditions had violations, Scenario 2 (eliminating non-permitted direct human inputs) showed improvement and meets the standard. All other scenarios also met the standard. Scenario 2 also meets a geometric mean of 206 cfu/100mL. This scenario may be used as a first target, or Stage I, goal during the implementation of best management practices (BMPs).

Table 5.30 Allocation scenarios for reducing current bacteria loads in Reedy Creek (subwatersheds 41, 57).

	Percent Reductions to Existing Bacteria Loads						
		Wildlife Land Based		Agricultural Land Based	Human Direct	Human and Pet Land Based	VADEQ *E. coli* Standard percent violations
Scenario	Wildlife Direct	Barren, Commercial, Forest, HIR, Wetlands	Livestock Direct	Cropland, Pasture, LAX	Straight Pipes	LMIR	>126 GM
1	0	0	0	0	0	0	10.0
2[1,2,*]	0	0	0	0	100	0	0
3	0	0	100	0	100	0	0
4	0	0	90	50	100	50	0
5	0	0	100	100	100	100	0

[1]Final TMDL Scenario
[2]Meets a GM of 206 cfu/100mL; possible Stage I scenario
*Subsequent 2006 - 2007 monthly bacterial data at 5 sites on Reedy Creek indicate that these upstream segments are impaired to a greater degree than the listed segment, and reductions of human and pet land-based loads should be considered during the Implementation Planning phase. Modeling to address additional monitoring data will be done in more detail during the implementation plan development.

Figure 5.9 shows the existing and allocated monthly geometric mean *E. coli* concentrations from Reedy Creek impairment outlet. This graph shows existing conditions in black, with allocated conditions overlaid in blue.

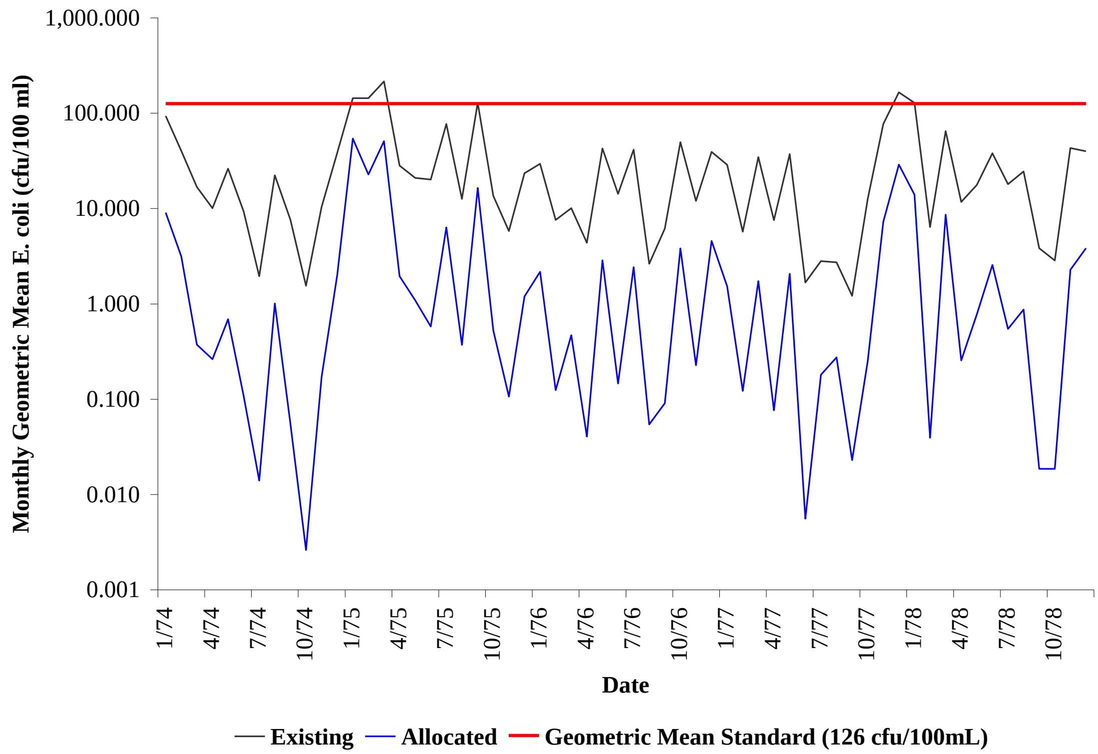

Figure 5.9 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 41, Reedy Creek impairment outlet.

Table 5.31 contains estimates of existing and allocated in-stream *E. coli* loads at the Reedy Creek impairment outlet reported as average annual cfu per year. The estimates in Table 5.31 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126-cfu/100mL geometric mean standard are given in the final column. The only reductions needed in Reedy Creek were from straight pipes and sewer overflows; this load was less than the typical load calculated for the future growth (1% of the TMDL). Therefore, the future growth was calculated as half of the straight pipe load. If the future growth load is needed for a future permit as 1% of the TMDL, reductions would need to be made to another bacteria source. A 1% reduction from low and medium intensity residential (LMIR) would be enough reduction to still meet the TMDL.

In Appendix C, Tables C.41 through C.44 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation. The percent reductions needed to meet zero percent violations of the water quality standard are given in the final column.

Table 5.31 Estimated existing and allocated *E. coli* in-stream loads in the Reedy Creek impairment.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Barren	3.62E+05	3.62E+05	0%
Commercial	1.23E+11	1.23E+11	0%
Cropland	0.00E+00	0.00E+00	0%
Forest	1.83E+10	1.83E+10	0%
Livestock Access	0.00E+00	0.00E+00	0%
Low and Medium Density Residential	1.76E+14	1.76E+14	0%
Open Space	2.69E+12	2.69E+12	0%
Pasture	0.00E+00	0.00E+00	0%
Wetland	2.95E+04	2.95E+04	0%
Direct			
Human	4.31E+11	0.00E+00	100%
Livestock	1.38E+06	1.38E+06	0%
Wildlife	5.83E+10	5.83E+10	0%
Permitted Sources	0.00E+00	0.00E+00	0%
Future Growth	0.00E+00	2.15E+11	NA
Total Loads	**1.797E+14**	**1.795E+14**	**0.1%**

Monitoring data used during fecal coliform model calibration was collected from 10/1/1999 to 9/30/2003. This data had a violation rate of 0% (fecal coliform >400cfu/100mL). The results of the model showed a calibrated violation rate of 23% at the outlet of Reedy Creek (fecal coliform >400cfu/100mL) during this time period (Table 4.13). The *E. coli* data available during TMDL development showed a violation rate of

27% (*E. coli* >235cfu/100mL). More recent *E. coli* concentration data collected as the TMDL was being developed is shown in Table 5.32. The more recent Reedy Creek *E. coli* data has violation rates from 42% to 81%. Also additional BST data was collected in Reedy Creek during TMDL development (Table 5.33). These more recent results show more violations of the single sample standard, but also show a similar percentage breakdown between the four animal groups. Wildlife is still the most dominant source of fecal bacteria to Reedy Creek, with pet and livestock at the next highest percentages.

Table 5.32 Summary of *E. coli* (cfu/100 mL) data collected by VADEQ from January 2006 - June 2007.

Stream	Station	Date	Count	Min	Max	Mean	Median	Standard Deviation	Violation %
Reedy Creek	2-RDD000.19	01/06-06/07	18	34	7,700	763	285	1,775	50.0%
Reedy Creek	2-RDD000.99	01/06-12/06	12	27	7,200	1,018	115	2,097	41.7%
Reedy Creek	2-RDD001.57	01/06-03/08	16	5	8,000	1,939	730	2,535	81.3%
Reedy Creek	2-RDD002.61	01/06-12/06	11	13	8,000	983	170	2,360	45.5%
Reedy Creek	2-RDD003.61	01/06-12/06	11	28	6,900	943	170	2,022	45.5%

Table 5.33 Summary of bacterial source tracking results from water samples collected in the Reedy Creek impairment (2-RDD001.57).

Date	Number of Isolates	*E. coli*[1] (cfu/100 ml)	Percent Isolates classified as[2]:			
			Wildlife	Human	Livestock	Pet
1/30/2008	24	**1,070**	**100%**	0%	0%	0%
2/13/2008	9	**>2,000**	**44%**	**44%**	12%	0%
3/5/2008	21	**1,960**	**95%**	0%	5%	0%
4/14/2008	NVI	**>2,000**	NVI	NVI	NVI	NVI
5/14/2008	2	**1,380**	50%	0%	50%	0%
7/7/2008	24	**>2,000**	**88%**	4%	4%	4%
7/28/2008	15	**>2,000**	**60%**	0%	**40%**	0%
9/17/2008	24	**>2,000**	**67%**	0%	8%	**25%**
10/1/2008	9	**>2,000**	**67%**	0%	**33%**	0%
10/28/2008	17	**>2,000**	**24%**	**41%**	0%	**35%**
12/1/2008	16	**>2,000**	6%	**25%**	**63%**	6%
12/16/2008	23	**1,950**	**57%**	0%	**17%**	**26%**
Isolate and percent weighted average proportions of *E. coli*:			63%	9%	17%	11%

[1]**Bold** type indicates this sample violates the instantaneous standard (235 cfu/100mL).
[2]**Bold** type indicates a statistically significant value.
NVI=No Viable Isolates

The small pond/wetland near the outlet of Reedy Creek may have allowed for settling and die-off of bacteria, effectively treating the water in Reedy Creek and allowing the earlier data at DEQ station 2-RDD000.19 to show low bacteria concentrations. This pond/wetland was filling up with sediment and becoming less efficient in removing bacteria over time. The Forest Hill Park lake restoration was completed in October 2009, returning the depth of the 3.3 acre lake to 9 to 13 feet. The new data shows higher bacteria concentrations overall at the outlet station 2-RDD000.19. Data was also recently collected upstream (2-RDD001.57) of the pond/wetland, and these data show higher bacteria concentrations than were modeled. Even with this new information, it is believed that the calculated TMDLs in Tables 5.34 and 5.35 are still applicable and reasonable. This is because the endpoint (*E. coli* geometric mean of 126cfu/100mL) and the modeled stream flow have not changed. The difference would be in the existing loads and, therefore, the percent reductions from the updated existing bacteria load to the allocated load. It is anticipated that updated percent reductions will be determined during implementation plan development, and will, most likely, come from the low/medium intensity residential (LMIR) land use. There is no agricultural land and no livestock in the Reedy Creek watershed.

Table 5.34 shows the average annual TMDL, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet the existing water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The only reductions needed in Reedy Creek were from straight pipes and sewer overflows; this load was less than the typical load calculated for the future growth (1% of the TMDL). Therefore, the future growth was calculated as half of the straight pipe load.

The City of Richmond, Chesterfield County, and VDOT currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the Reedy Creek drainage area. There is currently no standardized methodology acceptable to all stakeholders for disaggregating the VDOT MS4 load from that of the municipality's MS4 load for assigning waste load allocations, due to the continuity of the drainage systems.

Therefore, each municipality MS4 permit and its adjacent portion of the VDOT MS4 permit were assigned an aggregated load in the TMDL.

Table 5.34 Final average annual cumulative in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Reedy Creek impairment.

Impairment	WLA	LA	MOS	TMDL
Reedy Creek	**6.12E+13**	**1.18E+14**	*Implicit*	**1.79E+14**
MS4 City of Richmond / *MS4 VDOT* [1]	*5.84E+13*			
MS4 Chesterfield County / *MS4 VDOT* [1]	*2.60E+12*			
Future Load [2]	*2.15E+11*			

[1] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[2] The WLA reflects an allocation for potential future permits issued for bacteria control.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for Reedy Creek are shown in Table 5.35.

Table 5.35 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Reedy Creek impairment.

Impairment	WLA	LA	MOS	TMDL[2]
Reedy Creek	**1.68E+11**	**2.52E+11**	*Implicit*	**4.20E+11**
MS4 City of Richmond *MS4 VDOT* [1]	*1.60E+11*			
MS4 Chesterfield County *MS4 VDOT* [1]	*7.11E+09*			
Future Load [3]	*5.90E+08*			

[1] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.
[3] The WLA reflects an allocation for potential future permits issued for bacteria control.

5.4.9 James River segments

Originally the James River within the City of Richmond TMDL was divided into three impaired segments with an upstream reach that was not impaired (subs 1 and 2). During the development of this project, subsequent 303(d)/305(b) lists have been completed and some James River segments were delisted. The James River (upper) segment (VAP-H39R-11) was delisted in 2006 by meeting the primary contact recreational use. This segment is the part of the James River that flows within subwatersheds 3 and 4.

A portion of the James River (lower) segment (VAP-H39R-08) was also delisted in 2008 by meeting the primary contact recreational use. The delisted segment flows within subwatersheds 5, 6 and half of 7; the upstream (Williams' Island Dam) and downstream (Boulevard Bridge) boundaries are shown in Figure 5.10. The updated impaired segment description is from the Boulevard Bridge to the fall line.

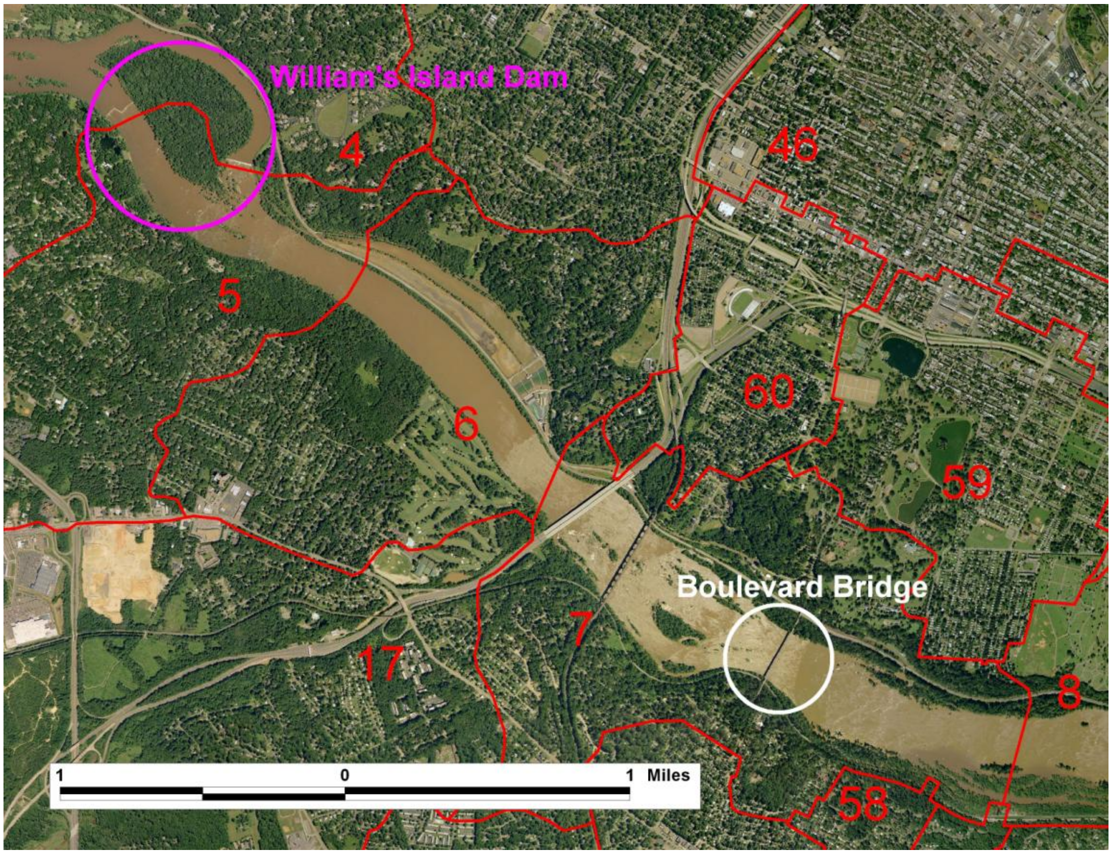

Figure 5.10 The location of the upper and lower boundaries of the delisted portion of the James River (lower) segment (VAP-H39R-08) and the subwatersheds in red.

TMDL tables were determined at the outlet of subwatershed 4 for the delisted segment VAP-H39R-11. Also, TMDL tables were determined at the outlet of subwatershed 6 for the delisted portion of VAP-H39R-08. These were created in case these segments are re-listed in the future. Because these waters flow into impairments, they are subject to the reductions required for the remaining VAP-H39R-08 segment from the Boulevard Bridge to the fall line. Therefore, the following TMDL tables represent loads that meet the current water quality standard and would be applicable if these segments are listed in the future.

5.4.9.1 Delisted James River (upper) segment VAP-H39R-11

For the recently delisted James River (upper) segment (VAP-H39R-11) at the outlet of subwatershed 4, Table 5.36 shows the average annual TMDL. This table gives the average amount of bacteria that can be present in the stream in a given year, and still meet the existing water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The City of Richmond, Henrico County, Chesterfield County, and VDOT currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the James River (upper) drainage area. In most cases, MS4 areas are overlapping or intertwined and there is currently no standardized methodology for disaggregating the MS4 loads to assign individual Waste Load Allocations. EPA, DEQ and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDL. To account for future growth of urban and residential human populations, five times the load from VA0024163, VA0063649, and VA0090727 was summed for future growth in the WLA portion.

Table 5.36 Final average annual cumulative in-stream *E. coli* bacterial loads (cfu/year) in the James River (upper) delisted segment.

Impairment	WLA	LA	MOS	TMDL
James River upper delisted (VAP-H39R-11)	**1.09E+13**	**1.69E+15**	*Implicit*	**1.70E+15**
VA0024163 [1]	*3.48E+10*			
VA0027910 [1]	*1.74E+11*			
VA0063649 [1]	*6.97E+09*			
VA0090727 [1]	*4.36E+11*			
MS4 City of Richmond / *MS4 VDOT* } [2]	*7.45E+11*			
MS4 Chesterfield County / *MS4 VDOT* } [2]	*1.46E+12*			
MS4 Henrico County / *MS4 VDOT* } [2]	*5.69E+12*			
Future Load [3]	*2.39E+12*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] The WLA reflects an allocation for potential future permits issued for bacteria control.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for James River (upper) are shown in Table 5.37.

Table 5.37 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) in the James River (upper) delisted segment.

Impairment		WLA	LA	MOS	TMDL[2]
James River upper delisted (VAP-H39R-11)		**3.00E+10**	**2.19E+14**		**2.19E+14**
VA0024163 [1]		*9.55E+07*		*Implicit*	
VA0027910 [1]		*4.77E+08*			
VA0063649 [1]		*1.91E+07*			
VA0090727 [1]		*1.19E+09*			
MS4 City of Richmond *MS4 VDOT*	} [3]	*2.04E+09*			
MS4 Chesterfield County *MS4 VDOT*	} [3]	*4.00E+09*			
MS4 Henrico County *MS4 VDOT*	} [3]	*1.56E+10*			
Future Load [4]		*6.54E+09*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.
[3] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[4] The WLA reflects an allocation for potential future permits issued for bacteria control.

5.4.9.2 Delisted James River (lower) segment VAP-H39R-08

For the recently delisted James River (lower) segment (VAP-H39R-08) at the outlet of subwatershed 6, Table 5.38 shows the average annual TMDL. This table gives the average amount of bacteria that can be present in the stream in a given year, and still meet the existing water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The City of Richmond, Chesterfield County, Henrico County, and VDOT currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the James River (lower) drainage area. In most cases, MS4 areas are overlapping or intertwined and there is currently no standardized methodology for disaggregating the MS4 loads to assign individual Waste Load Allocations. EPA, DEQ and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDL. To account for future growth of urban and residential human populations, five times the load from VA0024163, VA0063649, and VA0090727 was summed for future growth in the WLA portion.

Table 5.38 Final average annual cumulative in-stream *E. coli* bacterial loads (cfu/year) in the James River (lower) delisted segment.

Impairment	WLA	LA	MOS	TMDL
James River lower delisted (VAP-H39R-08)	**8.32E+13**	**2.40E+15**	*Implicit*	**2.48E+15**
VA0024163 [1]	*3.48E+10*			
VA0027910 [1]	*1.74E+11*			
VA0063649 [1]	*6.97E+09*			
VA0090727 [1]	*4.35E+11*			
MS4 City of Richmond *MS4 VDOT* } [2]	*8.11E+12*			
MS4 Chesterfield County *MS4 VDOT* } [2]	*2.47E+13*			
MS4 Henrico County *MS4 VDOT* } [2]	*4.74E+13*			
Future Load [3]	*2.39E+12*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] The WLA reflects an allocation for potential future permits issued for bacteria control.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for James River (lower) are shown in Table 5.39.

Table 5.39 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) in the James River (lower) delisted segment.

Impairment	WLA	LA	MOS	TMDL[2]
James River lower delisted (VAP-H39R-08)	**2.28E+11**	**2.18E+14**		**2.19E+14**
VA0024163 [1]	*9.55E+07*		*Implicit*	
VA0027910 [1]	*4.77E+08*			
VA0063649 [1]	*1.91E+07*			
VA0090727 [1]	*1.19E+09*			
MS4 City of Richmond / *MS4 VDOT* [3]	*2.22E+10*			
MS4 Chesterfield County / *MS4 VDOT* [3]	*6.77E+10*			
MS4 Henrico County / *MS4 VDOT* [3]	*1.30E+11*			
Future Load [4]	*6.54E+09*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.
[3] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[4] The WLA reflects an allocation for potential future permits issued for bacteria control.

5.4.9.3 Impaired James River (lower) segment VAP-H39R-08

Table 5.40 shows allocation scenarios used to determine the final TMDL for James River (lower) impaired segment. Because Virginia's standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational (swimming) use standard (126 cfu/100mL geometric mean). The existing condition, Scenario 1, shows the violation percentage with no reductions. Although the existing conditions had violations, Scenario 2 (eliminating non-permitted direct human inputs) showed improvement. Scenario 3 showed that eliminating direct livestock would slightly benefit water quality. A typical management scenario, Scenario 4, slightly improved water quality. This scenario showed improvement, but the standard was still not met. Scenario 5 shows 100% reductions to all anthropogenic sources; however, exceedances persisted. This scenario shows that reductions to wildlife loads or CSO loads must be made. The first 5 scenarios are explained in more detail in Section 5.4.

Scenario 6 shows the existing conditions with all upstream impairments allocated. The upstream impairments include Bernards Creek (Section 5.4.2), Powhite Creek (Section 5.4.7), Reedy Creek (Section 5.4.8), and Tuckahoe Creek (subwatersheds 26-28; separate report). Scenario 6 gets a 10% reduction in violations from the existing conditions, but does not meet the standard. All subsequent scenarios include the upstream impaired streams at allocated conditions. Scenario 7 shows Richmond's CSO Alternative E plan with no other load reductions. (Alternative E is explained in Section 5.4 and Greeley and Hanson, 2006 and Appendix E, Figure E.1.) This scenario did not meet the standard. The final TMDL was developed (Scenario 8) with a 96% reduction from direct livestock loads, a 99% reduction from low and medium intensity residential (LMIR) and agricultural nonpoint source loads, 100% correction of straight pipes and non-permitted sewer overflows, and a 63% reduction from land-based wildlife loads. These reductions are applicable for all areas in this project that contribute to the James River at subwatershed 9, excluding the impaired segments that have individual allocations. These subwatersheds are 1-9, 24-25, 41, 47-51, 55-60, and 76.

Scenario 9 meets a geometric mean of 206 cfu/100mL. This is not a standard; however, this scenario may be used as a first target, or Stage I, goal during the implementation of best management practices (BMPs). This scenario had an 88% reduction from direct livestock loads, a 91% reduction from low and medium intensity residential (LMIR), an 85% reduction from agricultural nonpoint source loads, and a 100% correction of straight pipes.

Table 5.40 Allocation scenarios for reducing current bacteria loads in James River (lower) (subwatersheds 1-9, 24-25, 41, 47-51, 55-60, 76).

Percent Reductions to Existing Bacteria Loads								
		Wildlife Land Based		Agricultural Land Based	Human Direct	Human and Pet Land Based	City of Richmond CSO Program Project Plan	VADEQ *E. coli* Standard percent violations
Scenario	Wildlife Direct	Barren, Commercial, Forest, HIR, Wetlands	Livestock Direct	Cropland, Pasture, LAX	Straight Pipes	LMIR	Scenario	>126 GM
1	0	0	0	0	0	0	Existing	53.33
2	0	0	0	0	100	0	Existing	50.00
3	0	0	100	0	100	0	Existing	48.33
4	0	0	90	50	100	50	Existing	35.00
5	0	0	100	100	100	100	Existing	10.00
Upstream Impairments Allocated:								
6	0	0	0	0	0	0	Existing	43.33
7	0	0	0	0	0	0	Alternative E	30.00
8[1]	0	63	96	99	100	99	Alternative E	0.00
9[2]	0	0	88	85	100	91	Alternative E	NA

[1]Final TMDL Scenario
[2]Meets a GM of 206 cfu/100mL; possible Stage I scenario

Figure 5.11 shows the existing and allocated monthly geometric mean *E. coli* concentrations from James River (lower) impairment outlet. This graph shows existing conditions in black, with allocated conditions overlaid in blue.

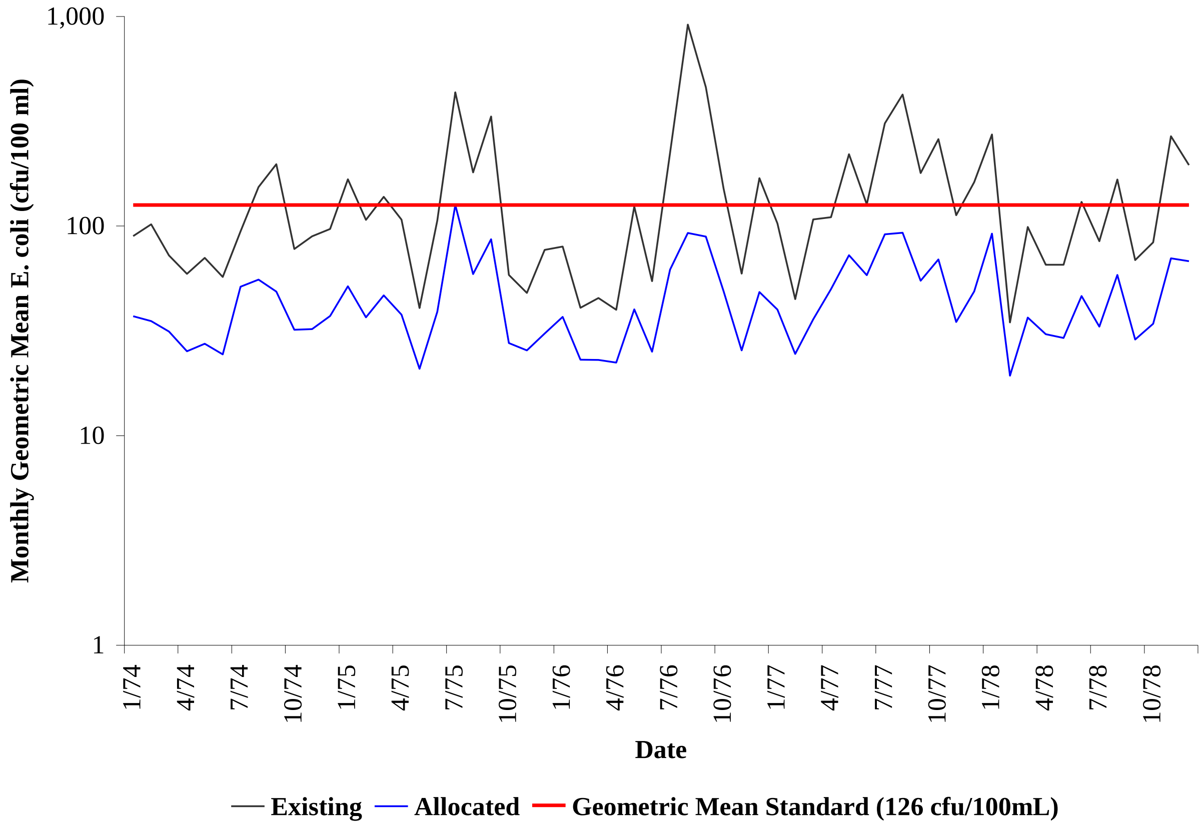

Figure 5.11 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 9, James River (lower) impairment outlet.

Table 5.41 contains estimates of existing and allocated in-stream *E. coli* loads at the James River (lower) impairment outlet reported as average annual cfu per year. The estimates in Table 5.42 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126-cfu/100mL geometric mean standard are given in the final column. The 67% reduction shown for the CSO load in Table 5.41 is due to the implementation of the City of Richmond's Long Term Control Plan – Alternative E and the reductions needed to the stormwater from residential and urban lands. No additional reductions are needed from the CSOs beyond those mentioned here.

In Appendix C, Tables C.21 through C.28 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.41 Estimated existing and allocated *E. coli* in-stream loads in the James River (lower) impairment.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Barren	1.41E+12	5.22E+11	63%
	Commercial	2.60E+14	9.61E+13	63%
	Cropland	1.64E+14	1.64E+12	99%
	Forest	1.19E+15	4.40E+14	63%
	Livestock Access	2.37E+12	2.37E+10	99%
	Low and Medium Density Residential	2.38E+17	2.38E+15	99%
	Open Space	1.24E+15	4.57E+14	63%
	Pasture	3.35E+15	3.35E+13	99%
	Wetland	2.58E+13	9.54E+12	63%
Direct				
	Human	2.90E+14	0.00E+00	100%
	Livestock	4.23E+13	1.69E+12	96%
	Wildlife	4.98E+13	4.98E+13	0%
	Permitted Sources	6.52E+11	6.52E+11	0%
	Future Growth	0.00E+00	2.39E+12	NA
CSOs	CSO Loads	9.12E+15	2.99E+15	67%*
Total Loads		**2.54E+17**	**6.46E+15**	**97.5%**

*The 67% reduction from CSO loads is estimated from the reduction from Alternative E and residential/urban reductions to stormwater

Table 5.42 shows the average annual TMDL, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet the existing water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The City of Richmond, Chesterfield County, Henrico County, and VDOT currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the James River (lower) drainage area. In most cases, MS4 areas are overlapping or intertwined and there is currently no standardized methodology for disaggregating the MS4 loads to assign individual Waste Load Allocations. EPA, DEQ and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDL. To account for future growth of urban and residential human populations, five times the load from VA0024163, VA0063649, and VA0090727 was summed for future growth in the WLA portion.

Table 5.42 Final average annual cumulative in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the James River (lower) impairment.

Impairment		WLA	LA	MOS	TMDL
James River (lower) impairment (VAP-H39R-08)		**3.06E+15**	**3.40E+15**		**6.46E+15**
VA0024163 [1]		*3.48E+10*		*Implicit*	
VA0027910 [1]		*1.74E+11*			
VA0063649 [1]		*6.97E+09*			
VA0090727 [1]		*4.36E+11*			
MS4 City of Richmond *MS4 VDOT*	} [2]	*1.79E+13*			
MS4 Chesterfield County *MS4 VDOT*	} [2]	*1.98E+13*			
MS4 Henrico County *MS4 VDOT*	} [2]	*3.50E+13*			
VA0063177: CSOs [3]		*2.99E+15*			
Future Load [4]		*2.39E+12*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] The WLA associated with the combined sewer system will be addressed through the performance standards for the facilities in the approved Long Term Control Plan (LTCP). If WQSs are not attained after the completion of CSO LTCP as determined by post-construction monitoring, additional steps may be required per EPA CSO Policy at IV.B.2.g.
[4] The WLA reflects an allocation for potential future permits issued for bacteria control.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for James River (lower) are shown in Table 5.43.

Table 5.43 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the James River (lower) impairment.

Impairment	WLA	LA	MOS	TMDL[2]
James River (lower) impairment (VAP-H39R-08)	**8.39E+12**	**2.14E+14**		**2.22E+14**
VA0024163 [1]	*9.55E+07*		Implicit	
VA0027910 [1]	*4.77E+08*			
VA0063649 [1]	*1.91E+07*			
VA0090727 [1]	*1.19E+09*			
MS4 City of Richmond *MS4 VDOT* } [3]	*4.90E+10*			
MS4 Chesterfield County *MS4 VDOT* } [3]	*5.43E+10*			
MS4 Henrico County *MS4 VDOT* } [3]	*9.60E+10*			
VA0063177: CSOs [4]	*8.18E+12*			
Future Load [5]	*6.54E+09*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.
[3] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[4] The WLA associated with the combined sewer system will be addressed through the performance standards for the facilities in the approved Long Term Control Plan (LTCP). If WQSs are not attained after the completion of CSO LTCP as determined by post-construction monitoring, additional steps may be required per EPA CSO Policy at IV.B.2.g.
[5] The WLA reflects an allocation for potential future permits issued for bacteria control.

5.4.9.4 Impaired James River (tidal) segment VAP-G01E-01

Table 5.44 shows allocation scenarios used to determine the final TMDL for James River (tidal) impaired segment. Because Virginia's standard does not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational (swimming) use standard (126 cfu/100mL geometric mean). The existing condition, Scenario 1, shows the violation percentage with no reductions.

Although the existing conditions had violations, Scenario 2 (eliminating non-permitted direct human inputs, upstream impairments allocated, and Alternative E) showed dramatic improvement and met the standard. (Alternative E is explained in Section 5.4 and Greeley and Hanson, 2006 and Appendix E, Figure E.1.) Scenario 2 includes downstream tidal inputs modeled at the fecal coliform standard of 200 cfu/100mL. The upstream impairments were at allocated conditions (Sections 5.41 through 5.4.9.3, and Tuckahoe Creek subwatersheds 26-28; separate report). Scenario 2 could also be used as a first target, or Stage I, goal during the implementation of best management practices (BMPs).

Table 5.44 Allocation scenarios for reducing current bacteria loads in James River (tidal) (subwatersheds 1-79).

	Percent Reductions to Existing Bacteria Loads							
		Wildlife Land Based		**Agricultural Land Based**	**Human Direct**	**Human and Pet Land Based**	**City of Richmond CSO Program Project Plan**	**VADEQ *E. coli* Standard percent violations**
Scenario	**Wildlife Direct**	**Barren, Commercial, Forest, HIR, Wetlands**	**Livestock Direct**	**Cropland, Pasture, LAX**	**Straight Pipes**	**LMIR**	**Scenario**	**>126 GM**
1	0	0	0	0	0	0	Existing	38.46
Upstream Impairments Allocated:								
2[1,2]	0	0	0	0	100	0	Alternative E	0.00

[1]Final TMDL Scenario
[2]Meets a GM of 206 cfu/100mL; possible Stage I scenario

Figure 5.12 shows the existing and allocated monthly geometric mean *E. coli* concentrations from James River (tidal) impairment outlet. This graph shows existing conditions in black, with allocated conditions overlaid in blue.

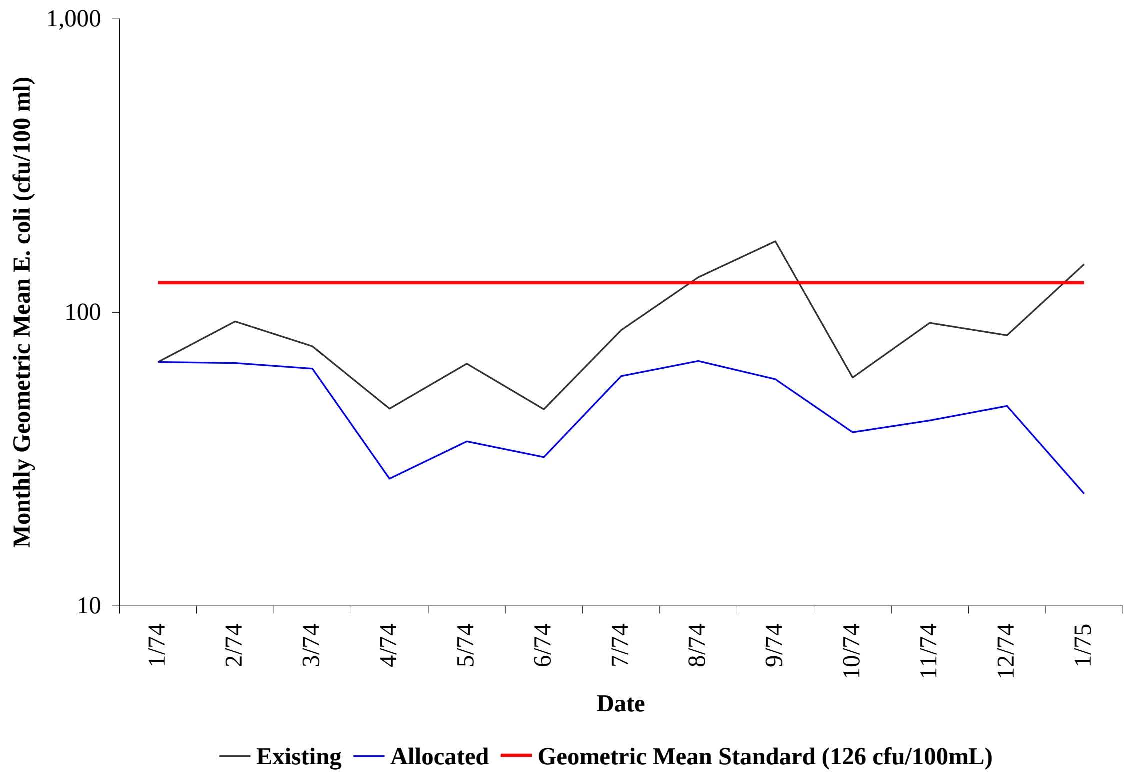

Figure 5.12 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 15, James River (tidal) impairment limiting subwatershed.

Table 5.45 contains estimates of existing and allocated in-stream *E. coli* loads at the James River (tidal) impairment outlet reported as average annual cfu per year. These loads are distributed based on their land-based origins, as opposed to their source origins. The in-stream load estimates at the impairment outlet in Table 5.45 assume that the in-stream source distribution of *E. coli* is the same as the distribution of fecal coliform on the land. The HSPF model is calibrated to the build-up and wash-off rates by subwatershed, not by individual bacteria source or land use. Any contributing bacteria loads from downstream tidal sources are distributed the same as the fecal coliform on the land. The estimates in Table 5.45 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed. The percent reductions needed to meet zero percent violations of the 126 cfu/100mL geometric mean standard are given in the final column. The 47% reduction shown for the CSO loads in Table 5.46 is due to the implementation of the City of Richmond's Long Term Control Plan – Alternative E, the reductions needed to the stormwater from residential and urban lands, and the CSO reductions in Gillie Creek and Almond Creek. No additional reductions are needed from CSOs beyond those mentioned here.

Table 5.45 Estimated existing and allocated *E. coli* in-stream loads in the James River (tidal) impairment.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Barren	2.01E+11	2.01E+11	0%
	Commercial	1.82E+11	1.82E+11	0%
	Cropland	9.82E+12	9.82E+12	0%
	Forest	1.73E+13	1.73E+13	0%
	Livestock Access	1.37E+12	1.37E+12	0%
	Low and Medium Density Residential	8.30E+13	8.30E+13	0%
	Open Space	2.61E+12	2.61E+12	0%
	Pasture	4.94E+13	4.94E+13	0%
	Wetland	5.11E+12	5.11E+12	0%
Direct				
	Human	4.82E+14	0.00E+00	100%
	Livestock	1.12E+13	1.12E+13	0%
	Wildlife	1.38E+13	1.38E+13	0%
	Permitted Sources	6.49E+14	6.49E+14	0%
	Future Growth	0.00E+00	8.82E+12	NA
CSOs	CSO Loads	5.69E+13	3.04E+13	47%*
Total Loads		**1.38E+15**	**8.82E+14**	**36.2%**

*The 47% reduction from CSO loads is estimated from the reductions from Alternative E, residential/urban reductions to stormwater, and CSO reductions in Gillie Creek and Almond Creek

In Appendix C, Tables C.29 through C.32 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.46 shows the average annual TMDL, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet the existing water quality standard. These values are output from the CE-QUAL-W2 model and incorporate in-stream die-off, tidal mixing, and other hydrological and environmental processes involved during runoff and stream routing techniques within the model framework. The City of Richmond, Chesterfield County, Henrico County, the Defense Supply Center – Richmond, John Tyler Community College, and VDOT currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the James River (tidal) drainage area. In most cases, MS4 areas are overlapping or intertwined and there is currently no standardized methodology for disaggregating the MS4 loads to assign individual WLAs. EPA, DEQ and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDL. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion. The City of Richmond has planned in their Phase III CSO Program Project Plan (Alternative E; Greeley and Hansen, 2006) to increase the capacity of the Richmond Wastewater Treatment Plant (permit #VA0063177) from 75 MGD to 255 MGD. This extra bacteria load is included in the WLA load for permit #VA0063177, but can be considered a future load.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. Specifically, the daily TMDL is calculated using the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The daily WLA is the annual divided by 365 and the daily LA is the difference between the TMDL and WLA. The daily average in-stream loads for James River (tidal) are shown in Table 5.47.

Table 5.46 Final average annual cumulative in-stream *E. coli* loads (cfu/year) modeled for TMDL allocation in the James River (tidal) impairment.

Impairment	WLA	LA	MOS	TMDL
James River (tidal) (VAP-G01E-01)	**6.97E+14**	**1.85E+14**	*Implicit*	**8.82E+14**
VA0002780 [1, 6]	*5.23E+12*			
VA0026557 [1]	*5.05E+12*			
VA0003077 [1]	*1.74E+12*			
VA0024163 [1]	*2.61E+10*			
VA0024996 [1]	*1.76E+13*			
VA0027910 [1]	*1.22E+11*			
VA0028622 [1]	*1.57E+11*			
VA0060194 [1]	*4.70E+13*			
VA0063177 [1]	*4.44E+14*			
VA0063649 [1]	*6.27E+09*			
VA0063690 [1]	*1.31E+14*			
VA0066494 [1]	*2.61E+10*			
VA0090727 [1]	*4.36E+11*			
VAG404219 [1]	*1.74E+09*			
VAG404078 [1]	*1.74E+09*			
VAG404208 [1]	*1.74E+09*			
VAG404145 [1]	*1.74E+09*			
VAG404175 [1]	*1.74E+09*			
VAG404201 [1]	*1.74E+09*			
VAG404238 [1]	*1.74E+09*			
VAG404223 [1]	*1.74E+09*			
VAG404029 [1]	*1.74E+09*			
VAG404247 [1]	*1.74E+09*			
VAG404224 [1]	*1.74E+09*			
VAG404033 [1]	*1.74E+09*			
VAG404248 [1]	*1.74E+09*			
MS4 Defense Supply Center – Richmond [2]	*4.49E+10*			
MS4 John Tyler Community College [2]	*5.03E+09*			
MS4 City of Richmond *MS4 VDOT* } [2, 3]	*9.43E+11*			
MS4 Chesterfield County *MS4 VDOT* } [2, 3]	*2.65E+12*			
MS4 Henrico County *MS4 VDOT* } [2, 3]	*1.36E+12*			
VA0063177: CSOs [4]	*3.04E+13*			
Future Growth [5]	*8.82E+12*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system.
[4] The WLA associated with the combined sewer system will be addressed through the performance standards for the facilities in the approved Long Term Control Plan (LTCP). If WQSs are not attained after the completion of CSO LTCP as determined by post-construction monitoring, additional steps may be required per EPA CSO Policy at IV.B.2.g.
[5] The WLA reflects an allocation for potential future permits issued for bacteria control.
[6] Facility currently operating at Tier 1 – industrial discharge, which is not believed to contribute bacteria. Upon the issuance of a Certificate To Operate (CTO) for Tiers 2 & 3, the municipal discharge WLA of 3.0 MGD will apply.

Table 5.47 Final average daily cumulative in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation - James River (tidal).

Impairment	WLA	LA	MOS	TMDL[2]
James River (tidal) (VAP-G01E-01)	**1.91E+12**	**3.32E+12**	*Implicit*	**5.23E+12**
VA0002780 [1, 7]	*1.43E+10*			
VA0026557 [1]	*1.38E+10*			
VA0003077 [1]	*4.77E+09*			
VA0024163 [1]	*7.16E+07*			
VA0024996 [1]	*4.82E+10*			
VA0027910 [1]	*3.34E+08*			
VA0028622 [1]	*4.30E+08*			
VA0060194 [1]	*1.29E+11*			
VA0063177 [1]	*1.22E+12*			
VA0063649 [1]	*1.72E+07*			
VA0063690 [1]	*3.58E+11*			
VA0066494 [1]	*7.16E+07*			
VA0090727 [1]	*1.19E+09*			
VAG404219 [1]	*4.77E+06*			
VAG404078 [1]	*4.77E+06*			
VAG404208 [1]	*4.77E+06*			
VAG404145 [1]	*4.77E+06*			
VAG404175 [1]	*4.77E+06*			
VAG404201 [1]	*4.77E+06*			
VAG404238 [1]	*4.77E+06*			
VAG404223 [1]	*4.77E+06*			
VAG404029 [1]	*4.77E+06*			
VAG404247 [1]	*4.77E+06*			
VAG404224 [1]	*4.77E+06*			
VAG404033 [1]	*4.77E+06*			
VAG404248 [1]	*4.77E+06*			
MS4 Defense Supply Center – Richmond [3]	*1.23E+08*			
MS4 John Tyler Community College [3]	*1.38E+07*			
MS4 City of Richmond *MS4 VDOT* } [3, 4]	*2.58E+09*			
MS4 Chesterfield County *MS4 VDOT* } [3, 4]	*7.24E+09*			
MS4 Henrico County *MS4 VDOT* } [3, 4]	*3.73E+09*			
VA0063177: CSOs [5]	*8.33E+10*			
Future Growth [6]	*2.42E+10*			

[1] Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion associated with the geometric mean may be used to assess progress toward TMDL goals.
[3] For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[4] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system.
[5] The WLA associated with the combined sewer system will be addressed through the performance standards for the facilities in the approved Long Term Control Plan (LTCP). If WQSs are not attained after the completion of CSO LTCP as determined by post-construction monitoring, additional steps may be required per EPA CSO Policy at IV.B.2.g.
[6] The WLA reflects an allocation for potential future permits issued for bacteria control.
[7] Facility currently operating at Tier 1 – industrial discharge, which is not believed to contribute bacteria. Upon the issuance of a CTO for Tiers 2 & 3, the municipal discharge WLA of 3.0 MGD will apply.

6. TMDL IMPLEMENTATION AND REASONABLE ASSURANCE

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources. The following sections outline the framework used in Virginia to provide reasonable assurance that the required pollutant reductions can be achieved.

6.1 Continuing Planning Process and Water Quality Management Planning

As part of the Continuing Planning Process, DEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the State Water Control Board (SWCB) for inclusion in the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

DEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as in the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on DEQ's web site under www.deq.state.va.us/export/sites/default/tmdl/pdf/ppp.pdf.

6.2 Staged Implementation

In general, Virginia intends for the required control actions, including Best Management Practices (BMPs), to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. The iterative implementation of pollution control actions in the watershed has several benefits:

1. It enables tracking of water quality improvements following implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;

3. It provides a mechanism for developing public support through periodic updates on implementation levels and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Bacteria reductions of 99% from low and medium intensity residential (LMIR), pasture, and cropland, a 96% reduction from direct livestock, 100% correction of straight pipes and non-permitted sewer overflows, and a 63% reduction from land-based wildlife loads in the contributing drainage area of the James River (lower) riverine impairment (VAP-H39R-08) do not reflect the recent delisting of upstream portions of the James River. The IP associated with this TMDL will acknowledge the attainability issues associated with these reductions and make appropriate accommodations to address the ability of reducing bacteria loadings in a cost-effective and efficient manner. The IP may include model scenarios that reflect the recent delisting of the included upper and lower segments.

It is expected that EPA will publish new or revised bacteria criteria by the end of 2012. The new criteria may change the indicator organism and/or the acceptable standard associated with inland freshwater. The IP will acknowledge the possible changes to the water quality standards.

6.3 Implementation of Waste Load Allocations

Federal regulations require that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). All such permits should be submitted to EPA for review.

For the implementation of the WLA component of the TMDL, the Commonwealth utilizes the Virginia NPDES program. Requirements of the permit process should not be duplicated in the TMDL process, and permitted sources are not usually addressed through the development of any TMDL implementation plans.

6.3.1 Treatment Plants

No reductions to waste treatment plants were required.

6.3.2 Stormwater

DEQ and DCR coordinate separate state permitting programs that regulate the management of pollutants carried by stormwater runoff. DEQ regulates stormwater discharges associated with industrial activities through its VPDES program, while DCR regulates stormwater discharges from construction sites, and from municipal separate storm sewer systems (MS4s) through the VSMP program. As with non-stormwater permits, all new or revised stormwater permits must be consistent with the assumptions and requirements of any applicable TMDL WLA. If a WLA is based on conditions specified in existing permits, and the permit conditions are being met, no additional actions may be needed. If a WLA is based on reduced pollutant loads, additional pollutant control actions will need to be implemented.

6.3.2.1 Municipal Separate Storm Sewer Systems – MS4s

For MS4/VSMP permits, the Commonwealth expects the permittee to specifically address the TMDL wasteload allocations for stormwater through the iterative implementation of programmatic BMPs. BMP effectiveness would be determined through permittee implementation of an individual control strategy that includes a monitoring program that is sufficient to determine its BMP effectiveness. As stated in EPA's Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002, "The NPDES permits must require the monitoring necessary to assure compliance under the permit limits". Ambient in-stream monitoring would not be an appropriate means of determining permit compliance. Ambient monitoring would be appropriate to determine if the entire TMDL is being met by ALL attributed sources. This is in accordance with recent EPA guidance. If future monitoring indicates no improvement in the quality of the regulated discharge, the permit could require the MS4 to expand or better tailor its stormwater management program to achieve the TMDL wasteload allocation. However, only failing to implement the programmatic BMPs identified in the modified stormwater management program would be considered a violation of the permit. Any changes to the TMDL resulting from water quality standards changes on the impaired segments would be reflected in the permit.

Wasteload allocations for stormwater discharges from storm sewer systems covered by a MS4 permit will be addressed as a condition of the MS4 permit. An implementation plan will identify types of corrective actions and strategies to obtain the load allocation for the pollutant causing the water quality impairment. Permittees will be required to participate in the development of TMDL implementation plans since recommendations from the process may result in modifications to the stormwater management plan in order to meet the TMDL. For example, MS4 permittees regulate erosion and sediment control programs that affect discharges that are not regulated by the MS4 permit.

Additional information on Virginia's Stormwater Program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at www.dcr.virginia.gov/soil_&_water/vsmp.shtml.

6.3.3 TMDL Modifications for New or Expanding Dischargers

Permits issued for facilities with wasteload allocations developed as part of a Total Maximum Daily Load (TMDL) must be consistent with the assumptions and requirements of these wasteload allocations (WLA), as per EPA regulations. In cases where a proposed permit modification is affected by a TMDL WLA, permit and TMDL staff must coordinate to ensure that new or expanding discharges meet this requirement. In 2005, DEQ issued guidance memorandum 05-2011 describing the available options and the process that should be followed under those circumstances, including public participation, EPA approval, State Water Control Board actions, and coordination between permit and TMDL staff. The guidance memorandum is available on DEQ's web site at www.deq.virginia.gov/waterguidance/.

6.3.4 Combined Sewer Overflow (CSO) Long Term Control Programs (LTCP)

EPA's CSO Control Policy (EPA CSO Policy) requires CSO communities to develop and implement LTCPs that provide for compliance with the applicable water quality-based requirements of the CWA (EPA, 1994). CSO communities may base the LTCPs on either the "presumption" approach, where the LTCP is presumed to provide for compliance with the applicable requirements if it meets one of several specified discharge criteria, or the "demonstration" approach, where the community must demonstrate through data, modeling and/or other acceptable methods that its LTCP will provide for compliance with applicable requirements (EPA, 1994; II.C.4). Permitting authorities are instructed to include LTCP-derived performance standards and requirements based on average design conditions in NPDES permits issued to those CSO communities that have developed LTCPs using the demonstration approach (EPA, 1994; IV.B.2.c). Performance standards are defined as the flow or volume capacity of the facilities identified in the LTCP. (The performance standard is allowed by EPA CSO Policy, Section IV.B.2.c.) Rainfall durations, frequencies and intensities vary from storm to storm and across CSO watersheds. Additionally, the periods between rainfall events vary and cause loads to build-up and wash off at different rates, which makes it infeasible to determine numerical effluent limitations for wet weather flows (WWFs) associated with the combined sewer system. The controls in the CSO LTCP, including WWF treatment controls at the WWTP, represent BMPs that may be designed to meet the CSO related WLAs from the TMDL (40 CFR §122.44(k) and 40 CFR §122.44(d)(1)(vii)(B)). The WLAs were developed based on the LTCP performance standards, which should achieve the WLAs using the same modeling that DEQ and/or the CSO communities used to derive the WLA for WWFs associated with operating the combined sewer system (40 CFR §122.44(d)(1)(vii)(B)). (40 CFR §122.44(d)(1)(vii)(B) requires the permitting authority to ensure that effluent limits developed to protect a narrative or numeric water quality standard are consistent with the assumptions and requirements of any available WLA for the discharge prepared by the State.) The CSO LTCP performance standards are the water quality-based effluent limitations for WWFs associated with facilities in the approved LTCP. If water quality standards (WQSs) are not attained after completion of a CSO LTCP as determined by post-construction monitoring, the EPA CSO Policy requires CSO communities to take additional steps to reach attainment of the WQSs, which may require the permittee to develop and implement additional controls (EPA, 1994; IV.B.2.g).

6.4 Implementation of Load Allocations

The TMDL program does not impart new implementation authorities. Therefore, the Commonwealth intends to use existing programs to the fullest extent in order to attain its water quality goals. The measures for non point source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the TMDL implementation plan.

6.4.1 Implementation Plan development

For the implementation of the TMDL's LA component, a TMDL implementation plan will be developed that addresses at a minimum the requirements specified in the Code of Virginia, Section 62.1-44.19:7. State law directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters". The implementation plan "shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments". EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process". The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

In order to qualify for other funding sources, such as EPA's Section 319 grants, additional plan requirements may need to be met. The detailed process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at www.deq.virginia.gov/tmdl/implans/ipguide.pdf.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of DEQ, DCR, and other cooperating agencies are technical resources to assist in this endeavor.

With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

6.4.2 Staged Implementation Scenarios

The purpose of the staged implementation scenarios is to identify one or more combinations of implementation actions that result in the reduction of controllable sources to the maximum extent practicable using cost-effective, reasonable BMPs for nonpoint source control. Among the most efficient sediment BMPs for both urban and rural watersheds are infiltration and retention basins, riparian buffer zones, grassed waterways, streambank protection and stabilization, and wetland development or enhancement. Among the most efficient bacterial BMPs for both urban and rural watersheds are stream side fencing for cattle farms, pet waste clean-up programs, and government or grant programs available to homeowners with failing septic systems and installation of treatment systems for homeowners currently using straight pipes. StageI scenarios were presented in Chapter5 in the allocation scenario tables.

Actions identified during TMDL implementation plan development that go beyond what can be considered cost-effective and reasonable will only be included as implementation actions if there are reasonable grounds for assuming that these actions will in fact be implemented.

If water quality standards are not met upon implementation of all cost-effective and reasonable BMPs, a Use Attainability Analysis (UAA) may need to be initiated since Virginia's water quality standards allow for changes to use designations if existing water quality standards cannot be attained by implementing effluent limits required under §301b and §306 of Clean Water Act, and cost effective and reasonable BMPs for nonpoint source control. Additional information on UAAs is presented in Section 6.6, Attainability of Designated Uses.

6.4.3 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the James River and in the Chesapeake Bay.

6.4.3.1 The City of Richmond's Long Term Control Plan

As mentioned in previous chapters, the City of Richmond has developed, and is currently implementing, a Long Term Control Plan (LTCP) to address CSO issues. The LTCP includes the goal of implementing Alternative E, which consists of increased storage capacity, outfall controls, outfall separations, and increased storage and treatment capacity at the Richmond Wastewater Treatment Plant. Most of the upgrades and improvements are completed for the upstream section of Richmond, whose stormwater flows into the riverine James River, the benefits of which are already measurable (Appendix B, Figures B.58 through B.60). Many improvements are scheduled on CSOs that flow into the tidal James River, Gillie Creek, and Almond Creek (Greeley and Hanson, 2006 and Appendix E, Figure E.1).

Gillie Creek and Almond Creek are unique in that even with the bacteria reductions expected with the implementation of Alternative E, these impaired streams still would not meet the primary contact recreational use standard in modeled scenarios. The TMDL IP will evaluate additional data and identify paths forward, which may include additional CSO controls in Gillie Creek and Almond Creek watersheds.

6.5 Implementation Funding Sources

The implementation of pollutant reductions from non-regulated nonpoint sources relies heavily on incentive-based programs. Therefore, the identification of funding sources for non-regulated implementation activities is a key to success. Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans". The TMDL Implementation Plan Guidance Manual contains information on a variety of funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

Some of the major potential sources of funding for non-regulated implementation actions may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program (also available for permitted activities), Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund (available for both point and nonpoint source pollution), tax credits, National Fish & Wildlife Foundation, VA Environmental Endowment, Chesapeake Bay Restoration, and landowner contributions.

With additional appropriations for the Water Quality Improvement Fund during the last two legislative sessions, the Fund has become a significant funding stream for agricultural BMPs and wastewater treatment plants. Additionally, funding is being made available to address urban and residential water quality problems. Information on WQIF projects and allocations can be found at www.deq.virginia.gov/bay/wqif.html and at www.dcr.virginia.gov/soil_&_water/wqia.shtml.

6.6 Follow-Up Monitoring

Following the development of the TMDL, DEQ will make every effort to continue to monitor the impaired streams in accordance with its ambient and biological monitoring programs. DEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with *DEQ Guidance Memo No. 03-2004* (www.deq.virginia.gov/waterguidance/pdf/032004.pdf), during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study. Since there may be a lag time of one-to-several years before any improvement in the benthic community will be evident, follow-up biological monitoring may not have to occur in the fiscal year immediately following the implementation of control measures.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the DEQ staff, in cooperation with DCR staff, the Implementation Plan

Steering Committee and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station. At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each DEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the DEQ regional TMDL coordinator by September 30 of each year.

DEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in DEQ's standard monitoring plan. Ancillary monitoring by citizens' or watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with DEQ monitoring data. In instances where citizens' monitoring data are not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or to monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at www.deq.virginia.gov/cmonitor/.

To demonstrate that the watershed is meeting water quality standards in watersheds where corrective actions have taken place (whether or not a TMDL or Implementation plan has been completed), DEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc) is bimonthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one year period.

6.7 Attainability of Designated Uses

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. To remove a designated use, the state must demonstrate that the use is not an existing use, and that downstream uses are protected. Such uses will be attained by implementing effluent limits required under §301b and §306 of Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10 paragraph I).

The state must also demonstrate that attaining the designated use is not feasible because:

1. Naturally occurring pollutant concentration prevents the attainment of the use;
2. Natural, ephemeral, intermittent or low flow conditions prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation;
3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;
4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use;
5. Physical conditions related to natural features of the water body, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection; or
6. Controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

This and other information is collected through a special study called a UAA. All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens, as well as the EPA, will be able to provide comment. Additional information can be obtained at:

www.deq.virginia.gov/wqs/designated.html.

The process to address potentially unattainable reductions based on the above is as follows: As a first step, measures targeted at the controllable, anthropogenic sources identified in the TMDL's staged implementation scenarios will be implemented. The expectation is that all controllable sources would be reduced to the maximum extent possible using the implementation approaches described above. DEQ will continue to monitor biological health and water quality in the stream during and subsequent to the implementation of these measures to determine if the water quality standard is attained. This effort will also help to evaluate if the modeling assumptions were correct. In the best-case scenario, water quality goals will be met and the stream's uses fully restored using effluent controls and BMPs. If, however, water quality standards are not being met, and no additional effluent controls and BMPs can be identified, a UAA would then be initiated with the goal of re-designating the stream for a more appropriate use or subcategory of a use.

A 2006 amendment to the Code of Virginia under 62.1-44.19:7E. provides an opportunity for aggrieved parties in the TMDL process to present to the State Water Control Board reasonable grounds indicating that the attainment of the designated use for a water is not feasible. The Board may then allow the aggrieved party to conduct a use attainability analysis according to the criteria listed above and a schedule established by the Board. The amendment further states that "If applicable, the schedule shall also address whether TMDL development or implementation for the water shall be delayed".

7. PUBLIC PARTICIPATION

Public participation during TMDL development for the James River – City of Richmond area was encouraged; a summary of the meetings is presented in Table 7.1. A kickoff meeting was held on April 4, 2006 for all five James River TMDL projects. Fifteen people attended representing state agencies, the City of Richmond and MapTech. The first technical advisory committee (TAC) and first public meeting were held on July 25, 2006. State agencies, Richmond city and MapTech representatives attended. Two final public meetings were held on March 10, 2009. Subsequent phone conferences and data exchanges facilitated the completion of this project and two supplemental public meetings were held to discuss changes resulting from public comments (6/30/2010). These public meetings were each preceded by a 30-minute question & answer session.

Table 7.1 Public participation during TMDL development for the James River – Hopewell to Westover study area.

Date	Location	Attendance[1]	Type
4/4/2006	DEQ Central Office	15	Kickoff
7/25/2006	DEQ Central Office	20	First TAC
7/25/2006	Virginia Commonwealth University - Student Commons Building	34	First public
3/10/2009	Virginia Commonwealth University - Student Commons Building	2pm: 30 6pm:17	2 Final public meetings
6/30/2010	DEQ's Piedmont Regional Office	2pm: 24 6pm: 6	Supplemental public meetings

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

Public participation during the implementation plan development process will include the formation of a stakeholder committee, with committee and public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. Stakeholder committees will have the express purpose of formulating the TMDL Implementation Plan. The committees will consist of, but not be limited to, representatives from VADEQ, VADCR, and local governments. These committees will have the responsibility for identifying corrective actions that are founded in practicality, establishing a time line to insure expeditious implementation, and setting measurable goals and milestones for attaining water quality standards.

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GLOSSARY

Note: All entries in italics are taken from USEPA (1998).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A waste load allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Alternative E. (See Appendix E) The final scenario chosen by the City of Richmond for their Long Term Control Plan (LTCP) dealing with the on-going updates to the city's combined sewer overflows (CSO).

Ambient water quality**.** *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

CFR. Code of Federal Regulations

CFU. Colony Forming Units

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

CSO. Combined Sewer Overflow

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition*. Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds*

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge Monitoring Report (DMR). *Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

Discharge permits (under NPDES)*. A permit issued by the EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for* *achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion*. The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should* *have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

EPA. Environmental Protection Agency

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Fate of pollutants*. Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph*. A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle*. The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology*. The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Impairment. A detrimental effect on the biological integrity of a water body that prevents attainment of the designated use.

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism*. An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Infiltration capacity*. The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff that travels just below the surface of the soil.

Isolate. An inbreeding biological population that is isolated from similar populations by physical or other means.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

LMIR. Low and medium intensity residential.

Loading, Load, Loading rate*. The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

LTCP. Long Term Control Plan

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by the EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Model. Mathematical representation of hydrologic and water quality processes. Effects of land use, slope, soil characteristics, and management practices are included.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nonpoint source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or* *water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Numeric targets*. A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Peak runoff*. The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (*e.g.*, pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by the EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/staged approach. *Under the phased approach to TMDL development, load allocations and waste load allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Privately owned treatment works*. Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period*. The time allowed for the public to express its views and concerns regarding action by the EPA or states (e.g., a* Federal Register *notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25^{th}, 50^{th}, and 75^{th} percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50^{th} quartile is also known as the median. The 25^{th} and 75^{th} quartiles are referred to as the lower and upper quartiles, respectively.

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reference Conditions. The chemical, physical, or biological quality or condition exhibited at either a single site or an aggregation of sites that are representative of non-impaired conditions for a watershed of a certain size, land use distribution, and other related characteristics. Reference conditions are used to describe reference sites.

Residence time. *Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration*. Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone*. The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient*. A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles. (Gilbert, 1987)

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Simulation. *The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor.

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (i.e. a low p-value indicates statistical significance).

Storm runoff. *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Technology-based standards. *Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Maximum Daily Load (TMDL). *The sum of the individual waste load allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

TMDL Implementation Plan (IP). A document required by Virginia statute detailing the suite of pollution control measures needed to remediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

TRC. Total Residual Chlorine. A measure of the effectiveness of chlorinating treated waste water effluent.

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

UAA. Use Attainability Analysis.

Urban Runoff. Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model). *Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Waste load allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.*

Wastewater treatment*. Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

WWTP. Wastewater treatment Plant

Water quality*. The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based permit*. A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria*. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by the EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard (WQS). *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WWF. Wet Weather Flow

WQIA. Water Quality Improvement Act.

APPENDIX A: FREQUENCY ANALYSIS OF BACTERIA CONCENTRATIONS

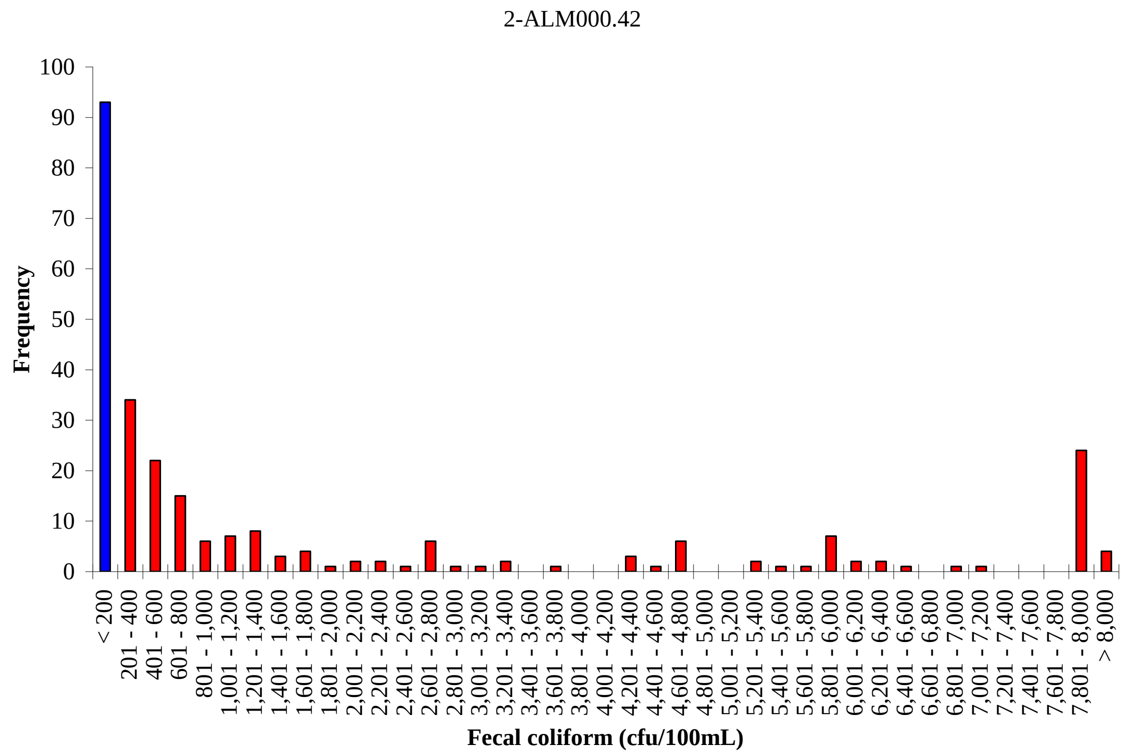

Figure A. 1 Frequency analysis of fecal coliform concentrations at station 2-ALM000.42 in the Almond Creek impairment from 5/72 to 5/03.

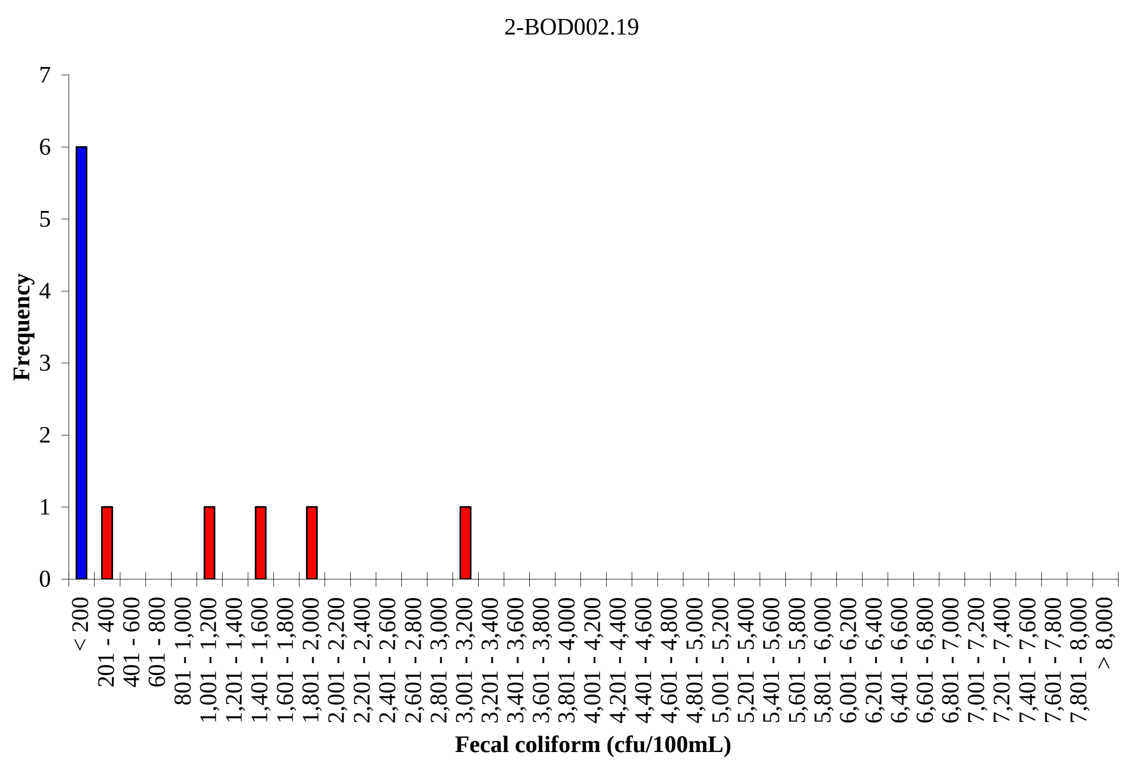

Figure A. 2 Frequency analysis of fecal coliform concentrations at station 2-BOR001.73 in the Bernards Creek impairment from 8/97 to 5/03.

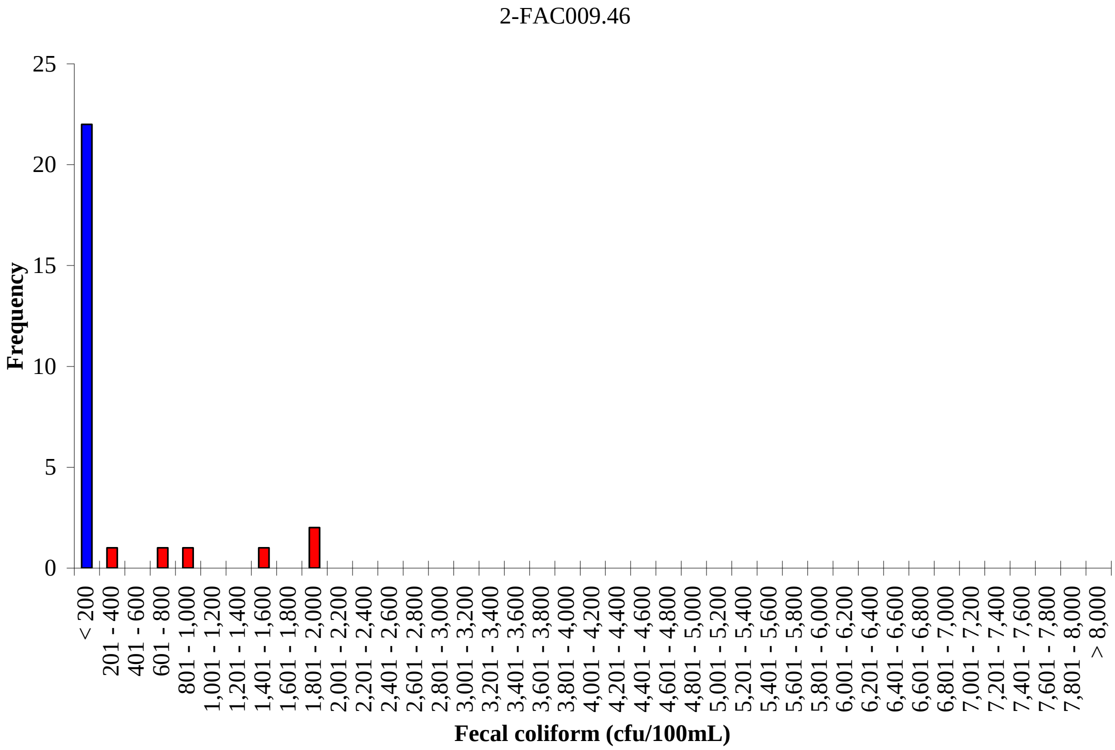

Figure A. 3 Frequency analysis of fecal coliform concentrations at station 2-FAC009.46 in the Falling Creek impairment from 5/01 to 11/05.

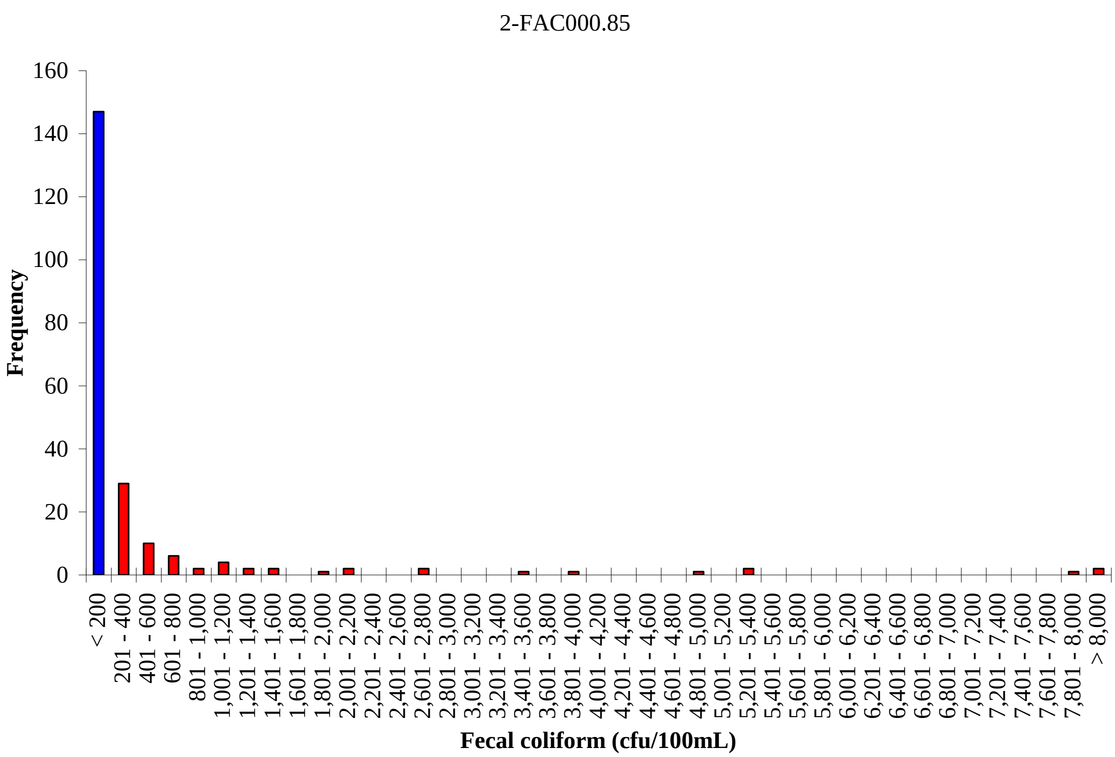

Figure A. 4 Frequency analysis of fecal coliform concentrations at station 2-FAC000.85 in the Falling Creek impairment from 1/80 to 3/06.

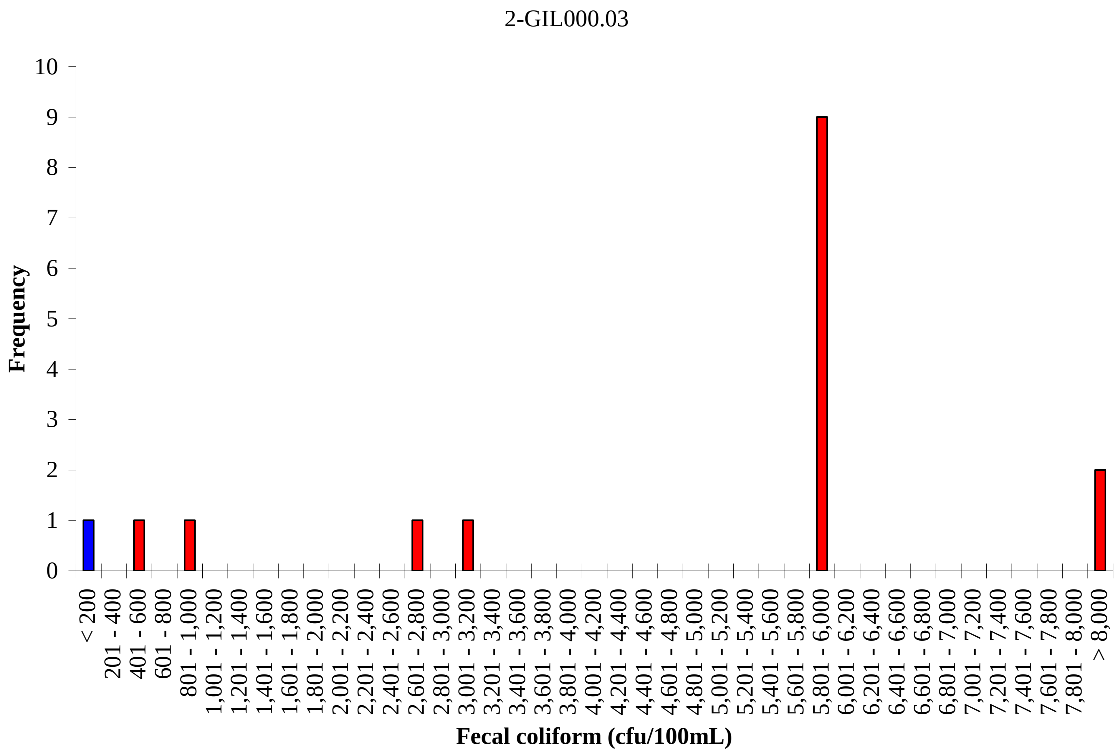

Figure A. 5 Frequency analysis of fecal coliform concentrations at station 3-GIL000.03 in the Gillie Creek impairment from 9/72 to 7/74.

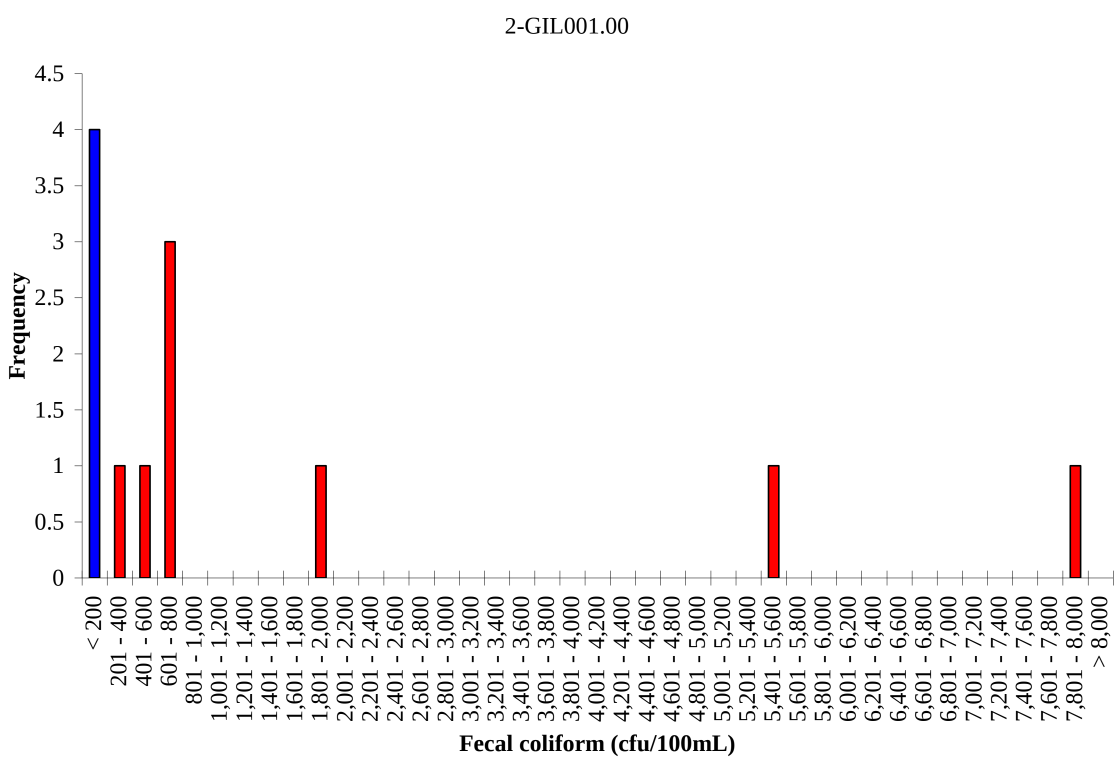

Figure A. 6 Frequency analysis of fecal coliform concentrations at station 2-GIL001.00 in the Gillie Creek impairment from 6/01 to 5/03.

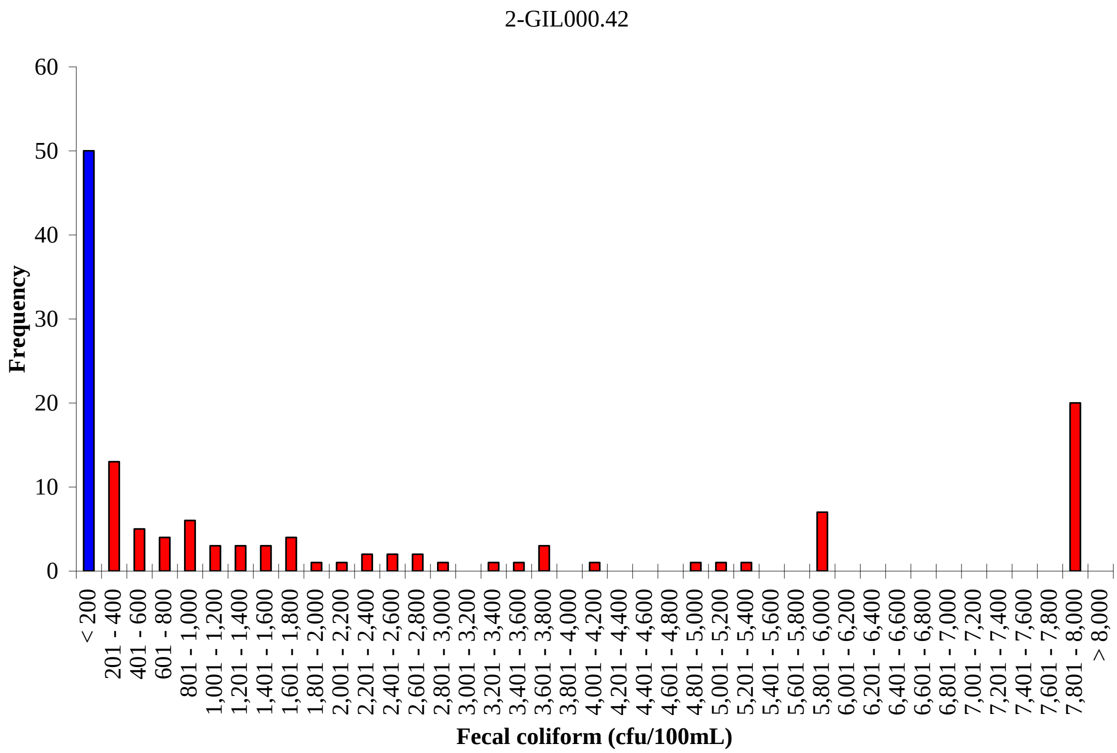

Figure A. 7 Frequency analysis of fecal coliform concentrations at station 2-GIL000.42 in the Gillie Creek impairment from 1/80 to 2/89.

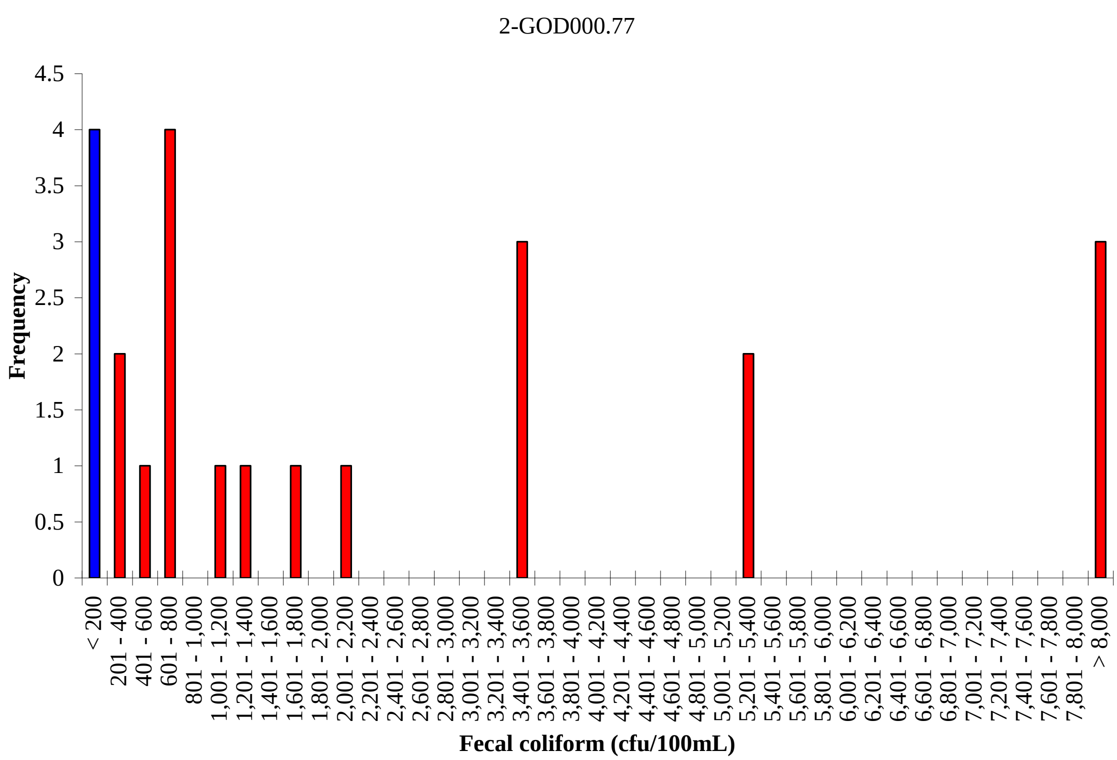

Figure A. 8 Frequency analysis of fecal coliform concentrations at station 2-GOD000.77 in the Goode Creek impairment from 8/97 to 4/01.

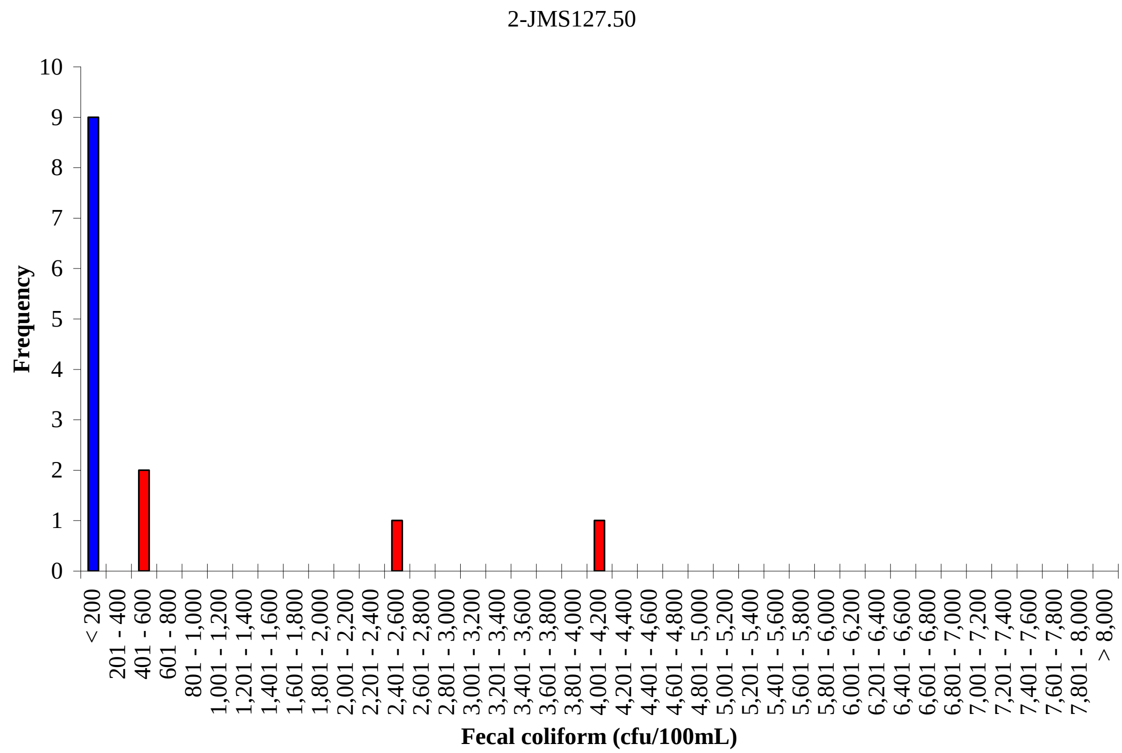

Figure A. 9 Frequency analysis of fecal coliform concentrations at station 2-JMS127.50 in the James River from 6/01 to 5/03.

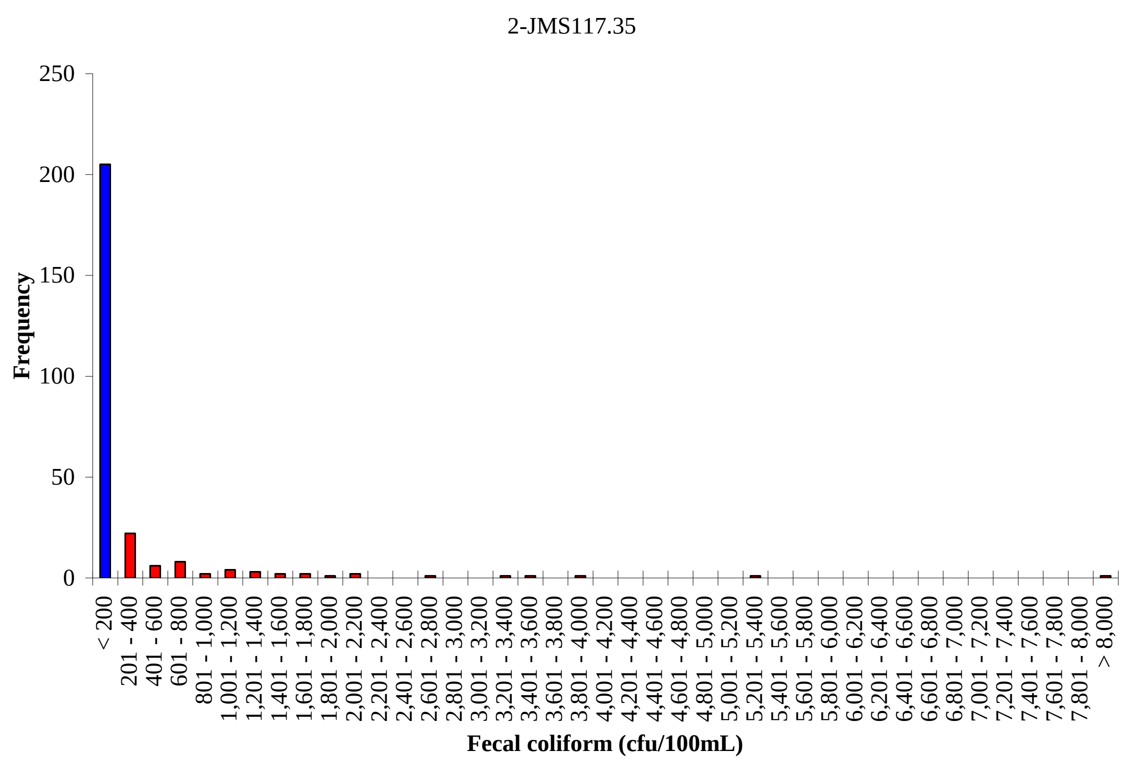

Figure A. 10 Frequency analysis of fecal coliform concentrations at station 2-JMS117.35 in the James River from 1/80 to 12/05.

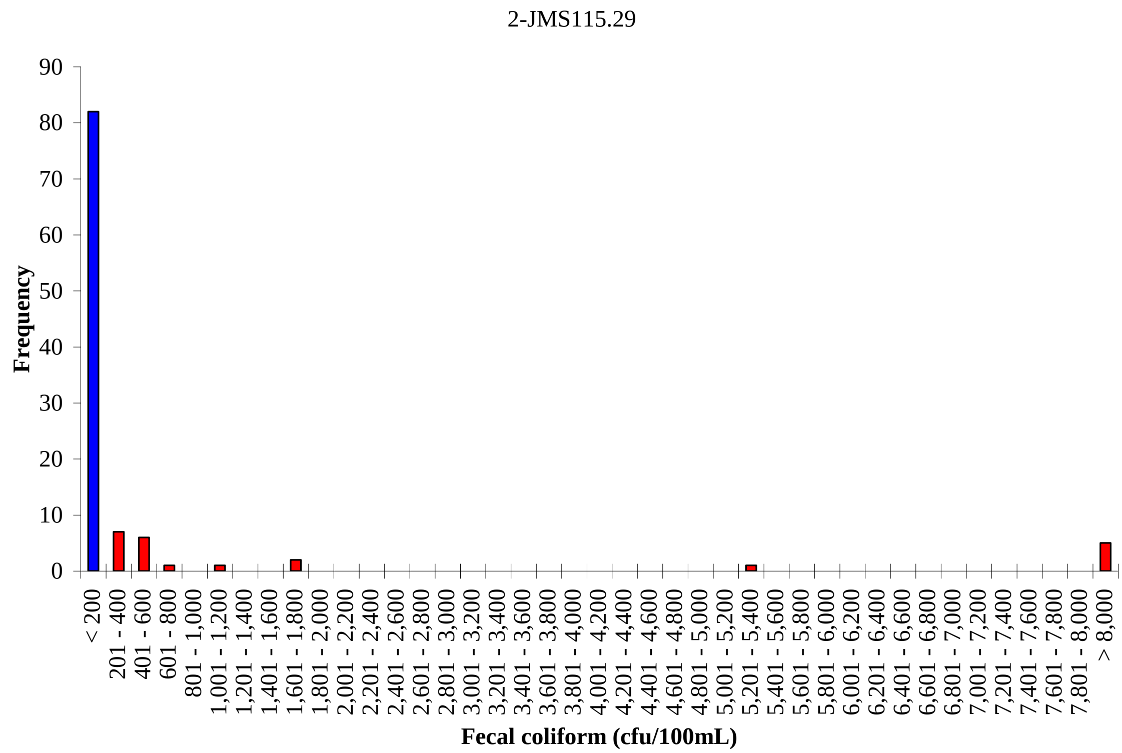

Figure A. 11 Frequency analysis of fecal coliform concentrations at station 2-JMS115.29 in the James River from 7/94 to 9/04.

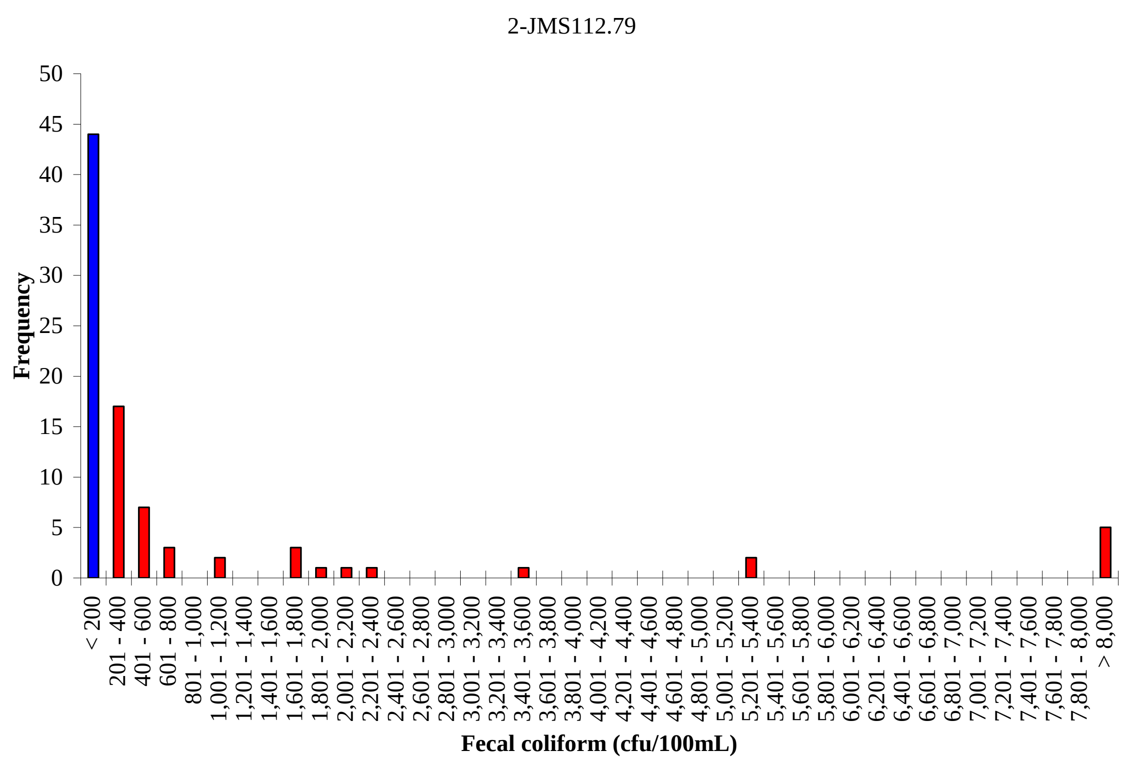

Figure A. 12 Frequency analysis of fecal coliform concentrations at station 2-JMS112.79 in the James River impairment from 9/95 to 9/04.

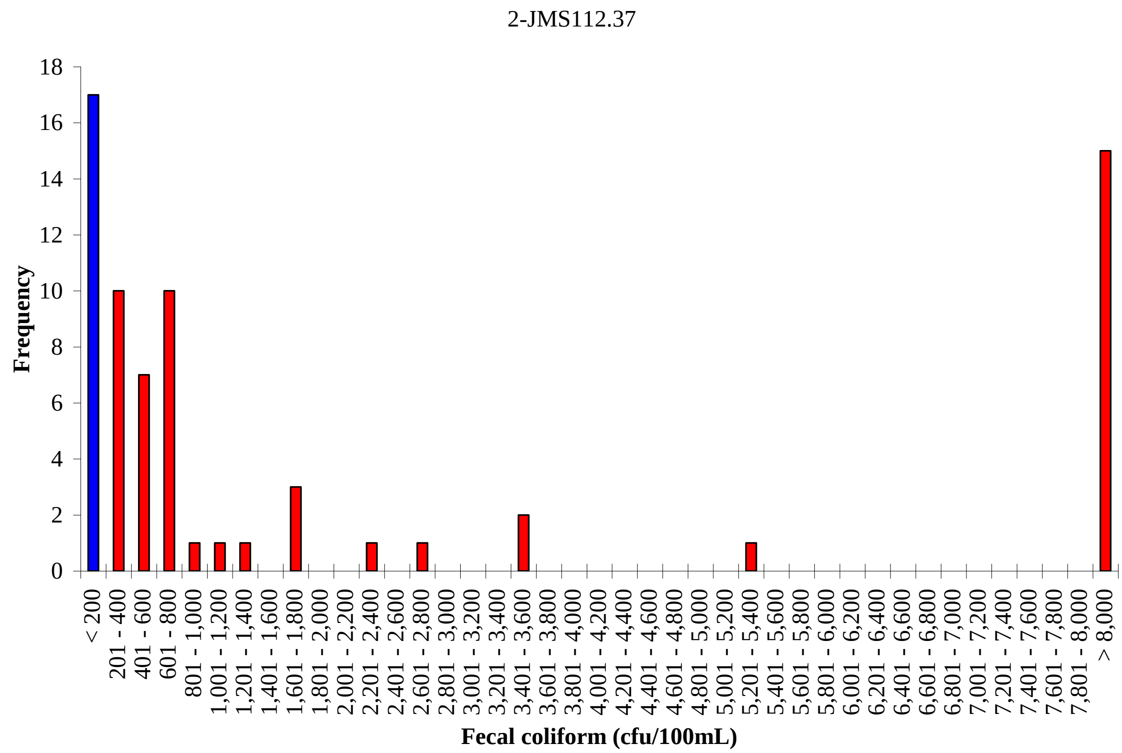

Figure A. 13 Frequency analysis of fecal coliform concentrations at station 2-JMS112.37 in the James River impairment from 9/95 to 8/01.

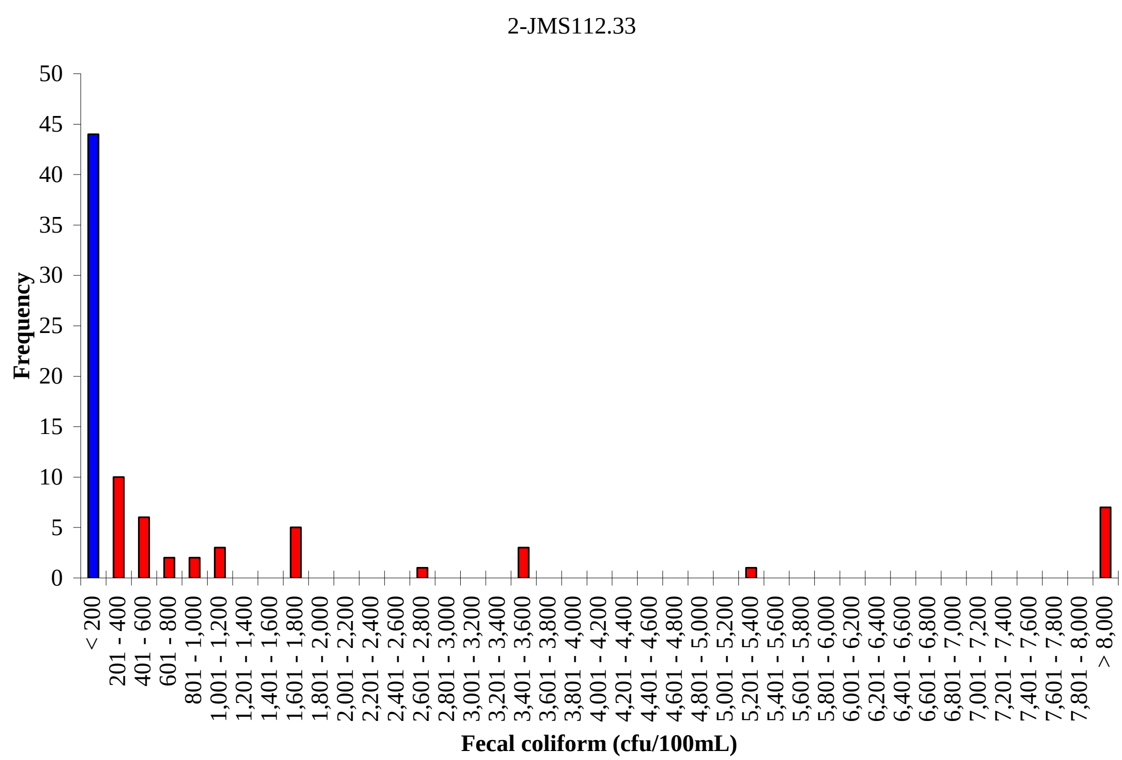

Figure A. 14 Frequency analysis of fecal coliform concentrations at station 2-JMS112.33 in the James River impairment from 9/95 to 8/04.

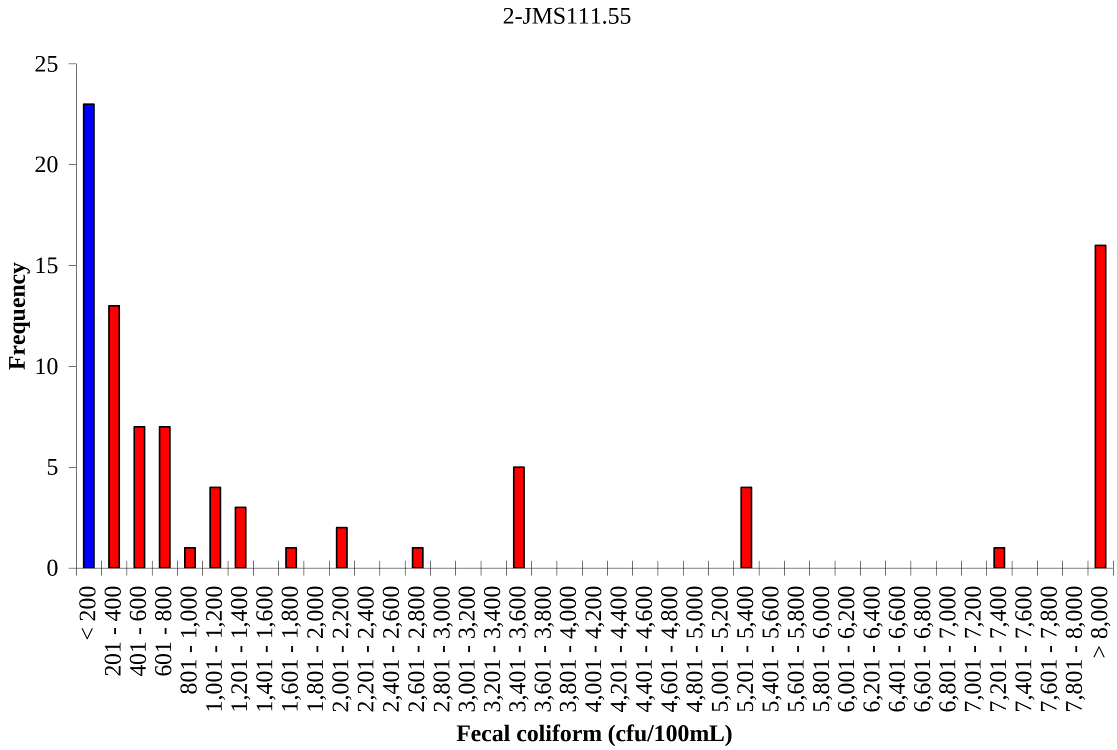

Figure A. 15 Frequency analysis of fecal coliform concentrations at station 2-JMS111.55 in the James River impairment from 6/94 to 8/01.

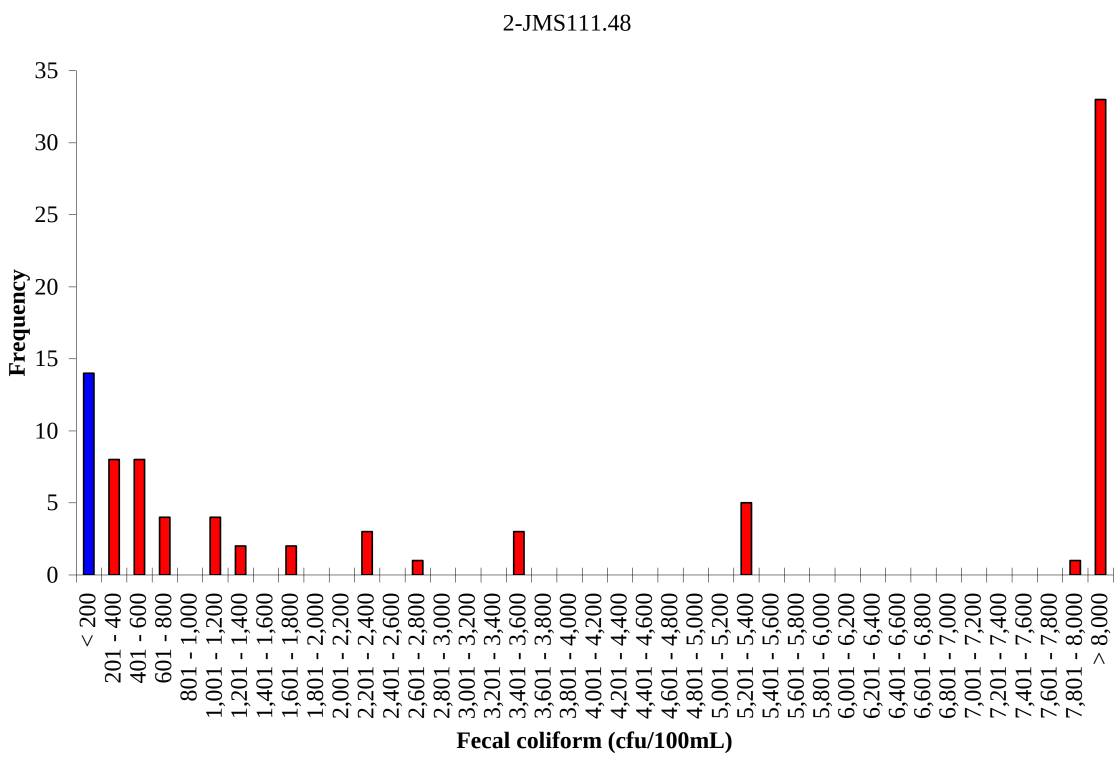

Figure A. 16 Frequency analysis of fecal coliform concentrations at station 2-JMS111.48 in the James River impairment from 6/94 to 8/01.

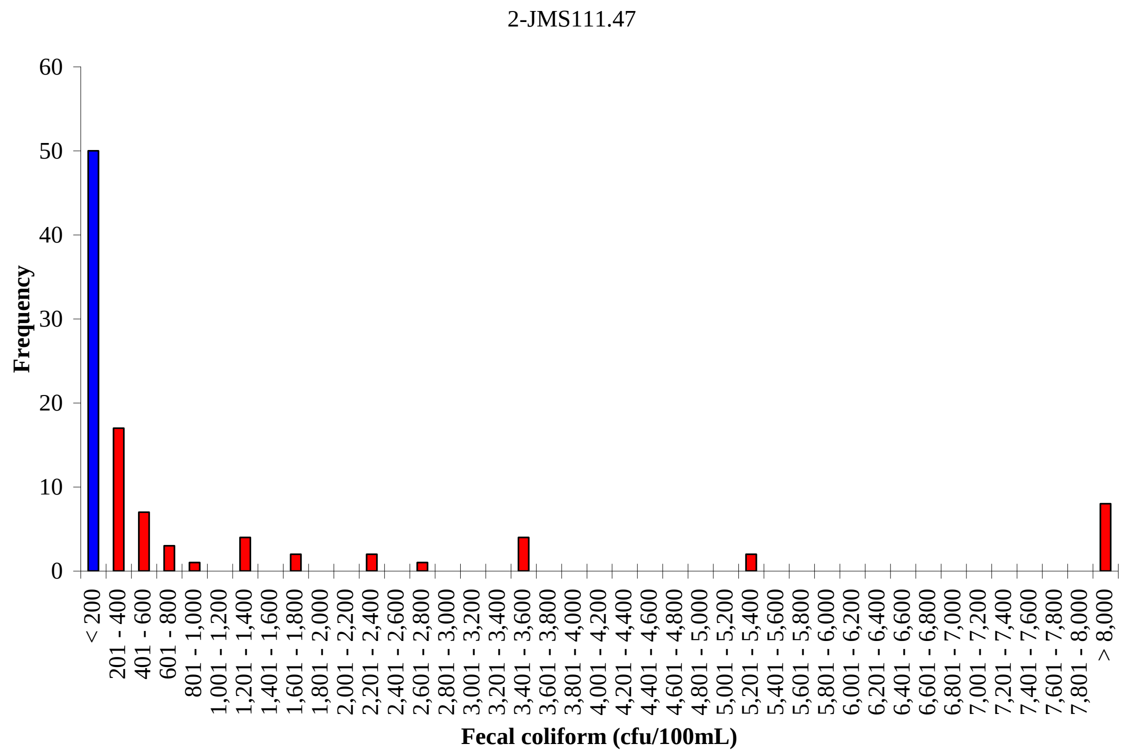

Figure A. 17 Frequency analysis of fecal coliform concentrations at station 2-JMS111.47 in the James River impairment from 7/94 to 8/04.

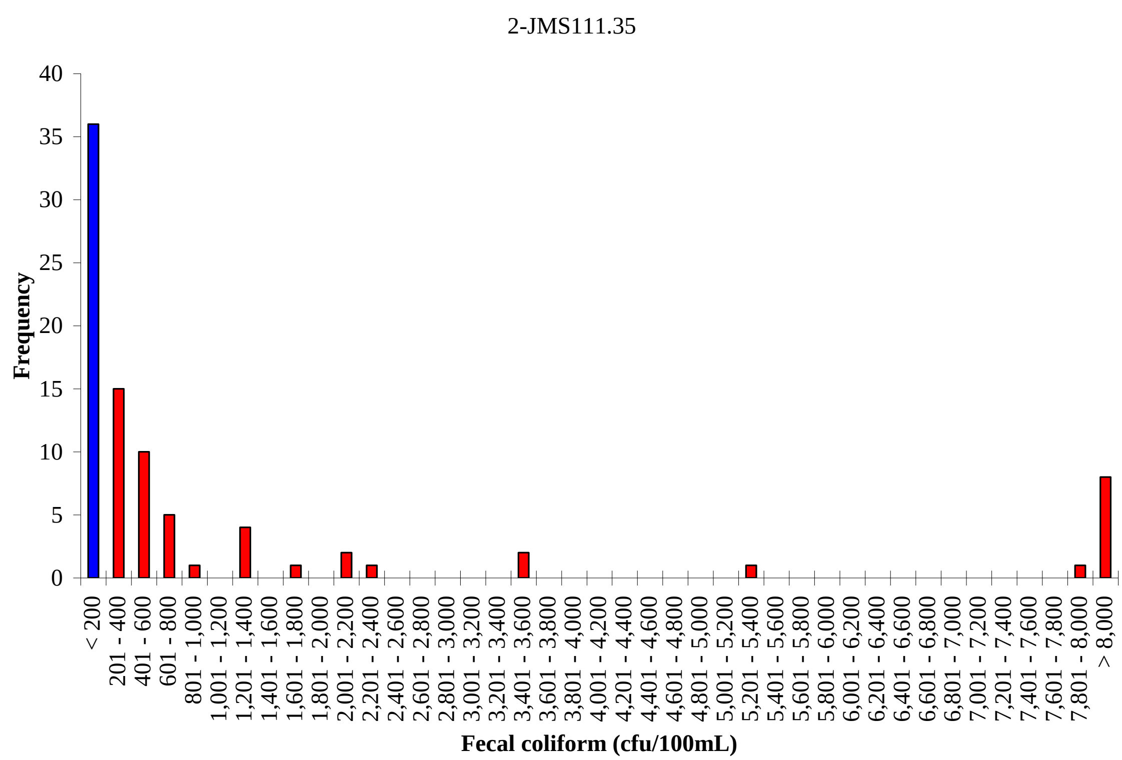

Figure A. 18 Frequency analysis of fecal coliform concentrations at station 2-JMS111.35 in the James River impairment from 6/94 to 8/01.

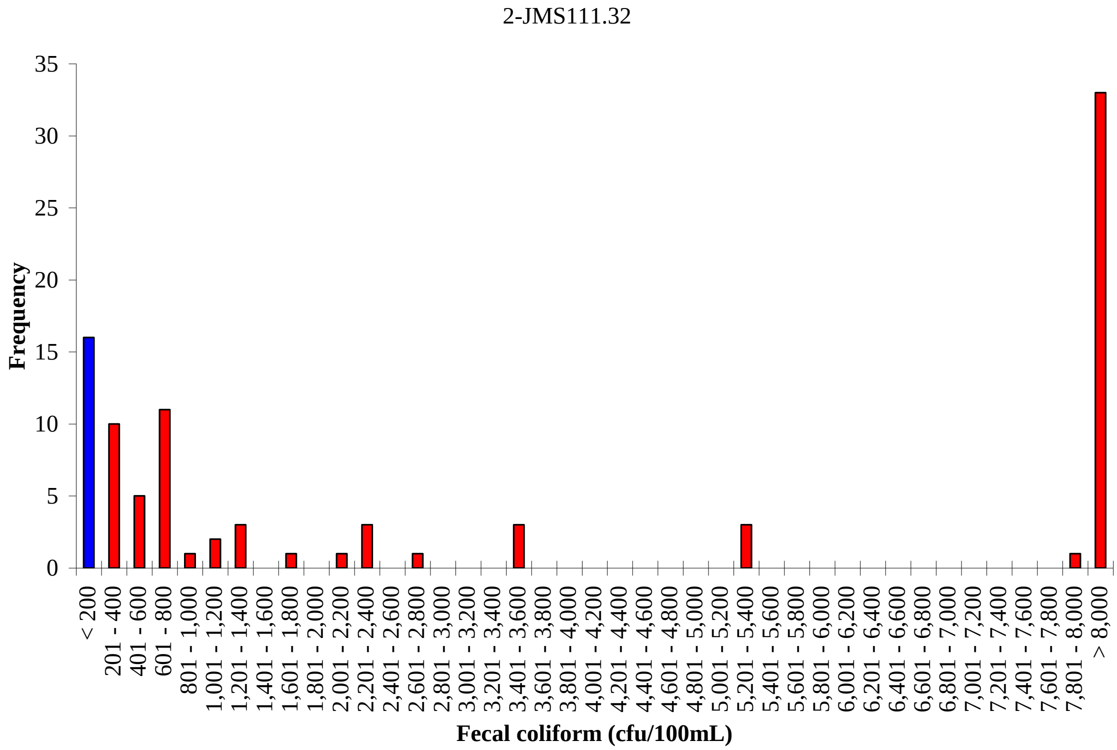

Figure A. 19 Frequency analysis of fecal coliform concentrations at station 2-JMS111.32 in the James River impairment from 6/94 to 8/01.

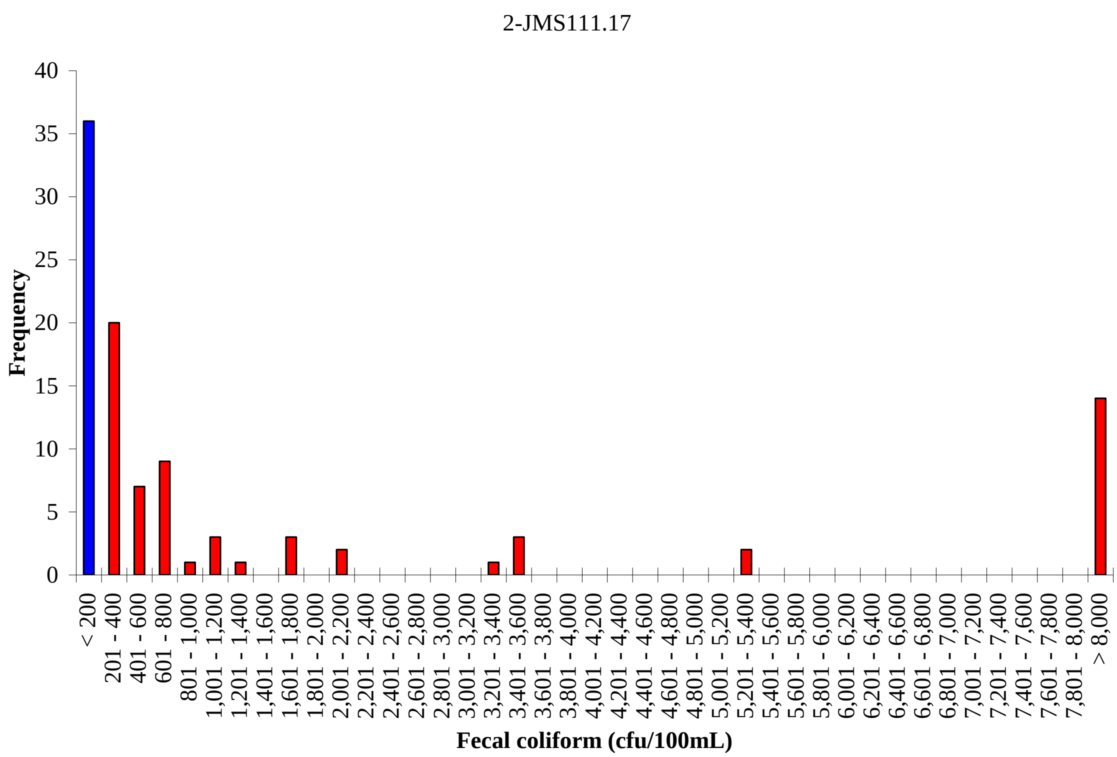

Figure A. 20 Frequency analysis of fecal coliform concentrations at station 2-JMS111.17 in the James River impairment from 9/95 to 8/04.

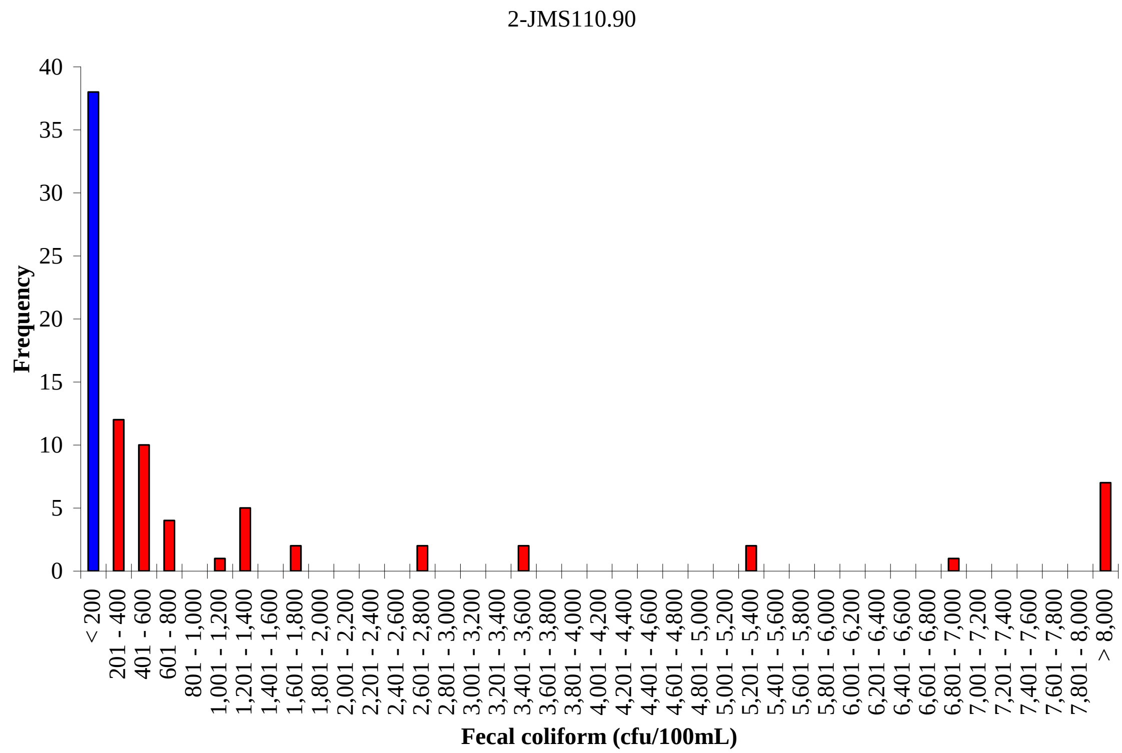

Figure A. 21 Frequency analysis of fecal coliform concentrations at station 2-JMS110.90 in the James River impairment from 6/94 to 8/01.

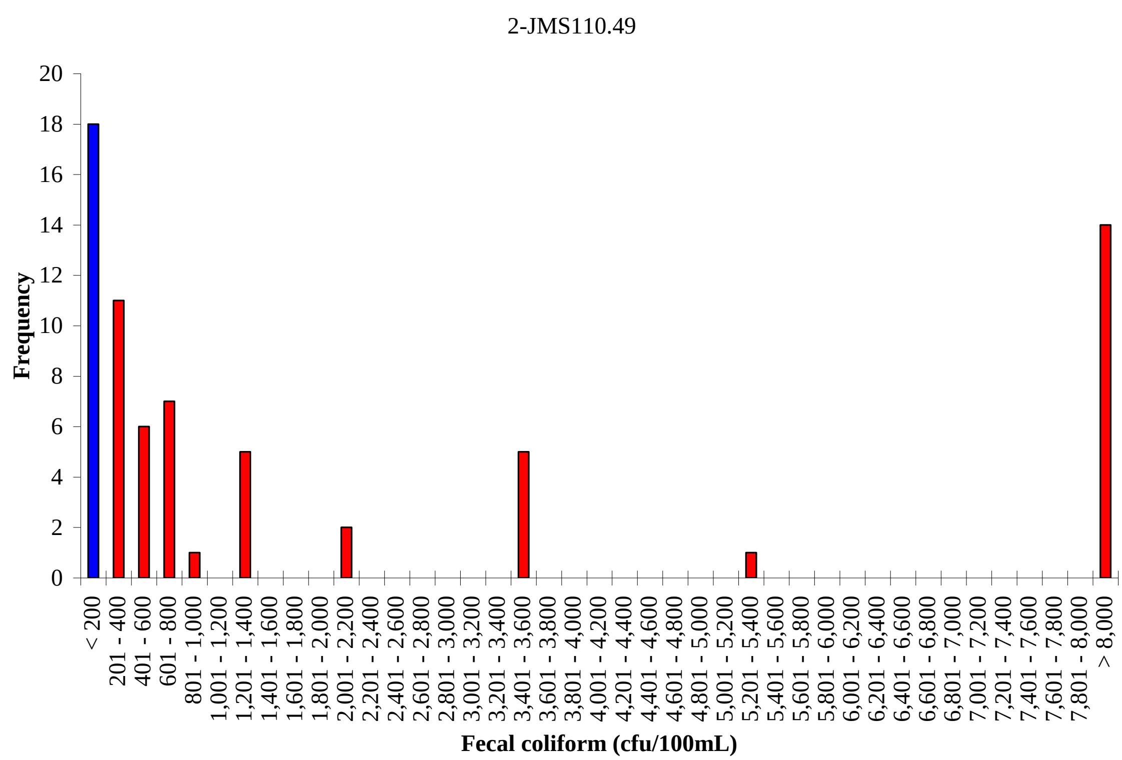

Figure A. 22 Frequency analysis of fecal coliform concentrations at station 2-JMS110.49 in the James River impairment from 9/95 to 8/01.

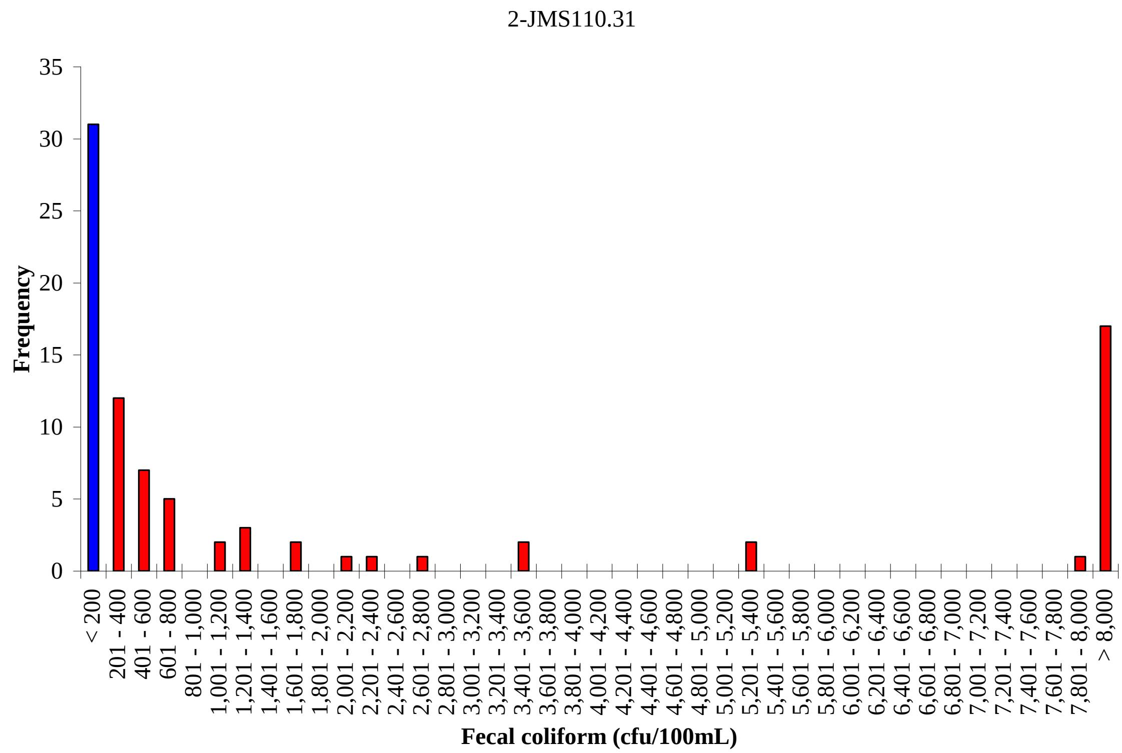

Figure A. 23 Frequency analysis of fecal coliform concentrations at station 2-JMS110.31 in the James River impairment from 6/94 to 8/01.

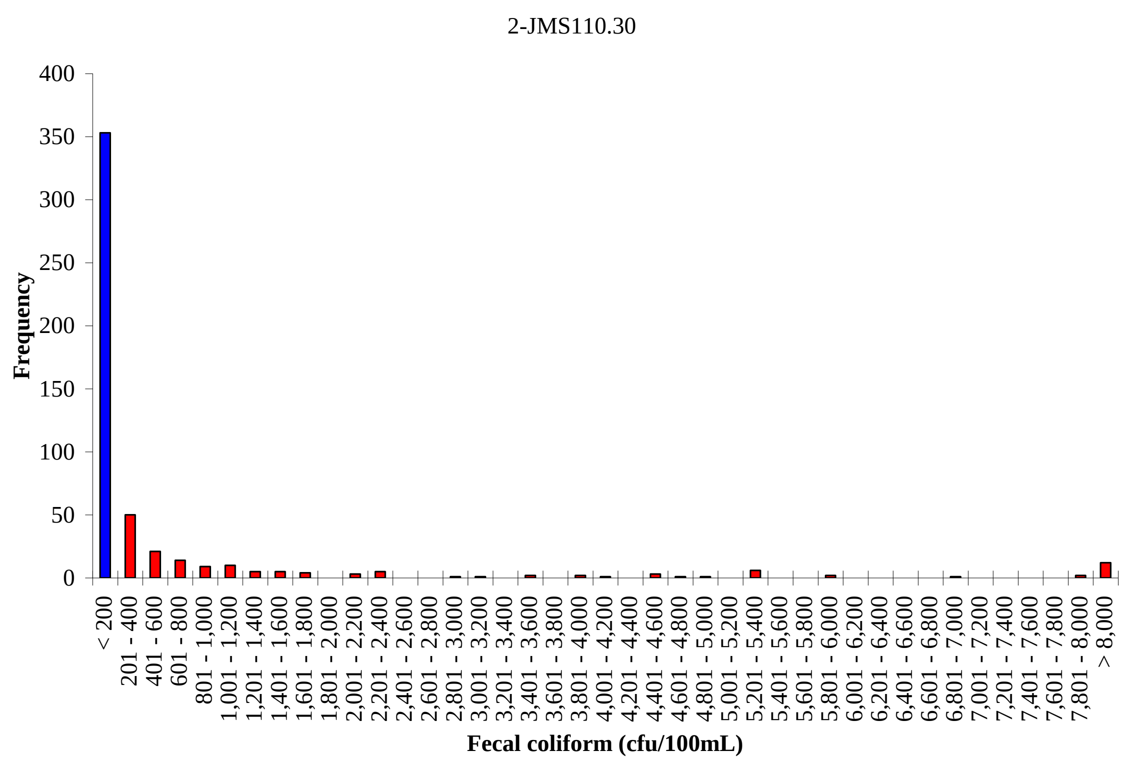

Figure A. 24 Frequency analysis of fecal coliform concentrations at station 2-JMS110.30 in the James River impairment from 1/80 to 1/06.

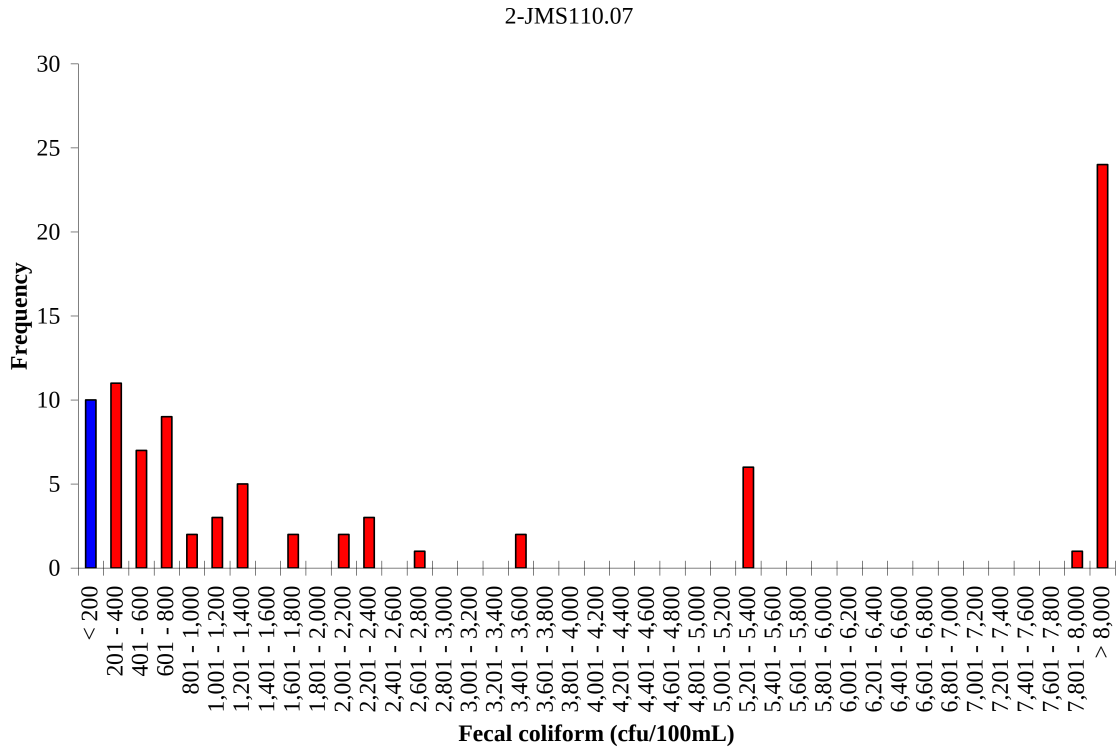

Figure A. 25 Frequency analysis of fecal coliform concentrations at station 2-JMS110.07 in the James River impairment from 6/94 to 8/01.

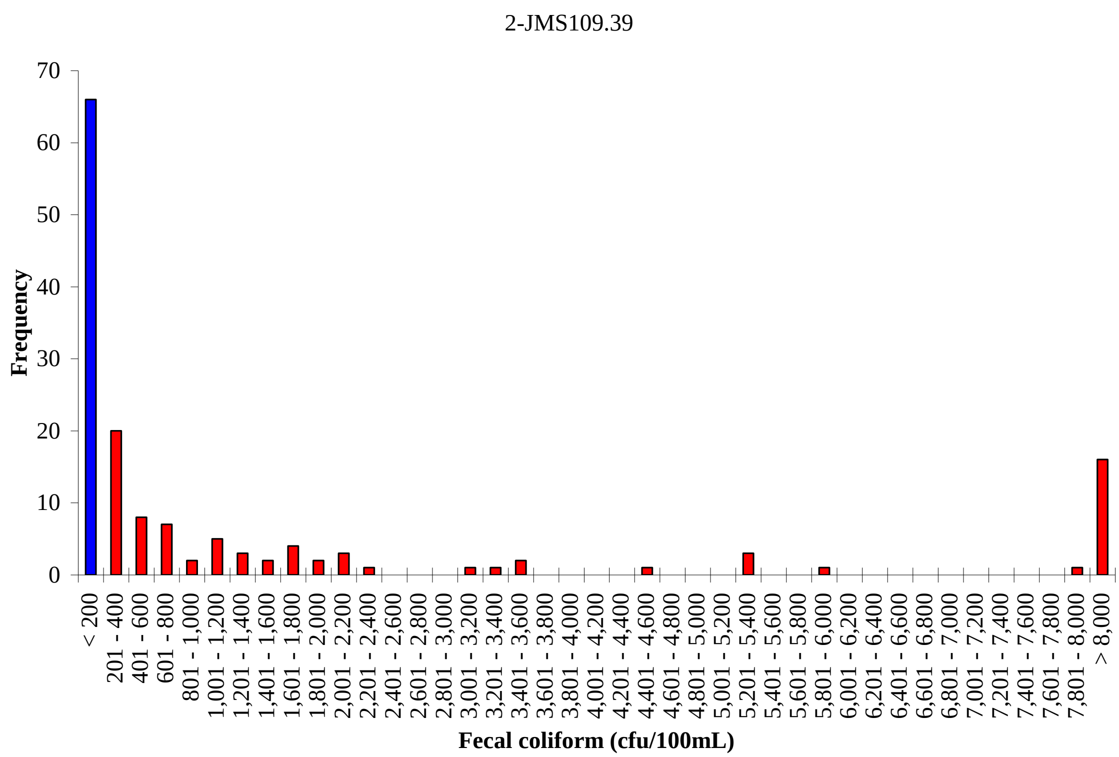

Figure A. 26 Frequency analysis of fecal coliform concentrations at station 2-JMS109.39 in the James River impairment from 5/80 to 8/01.

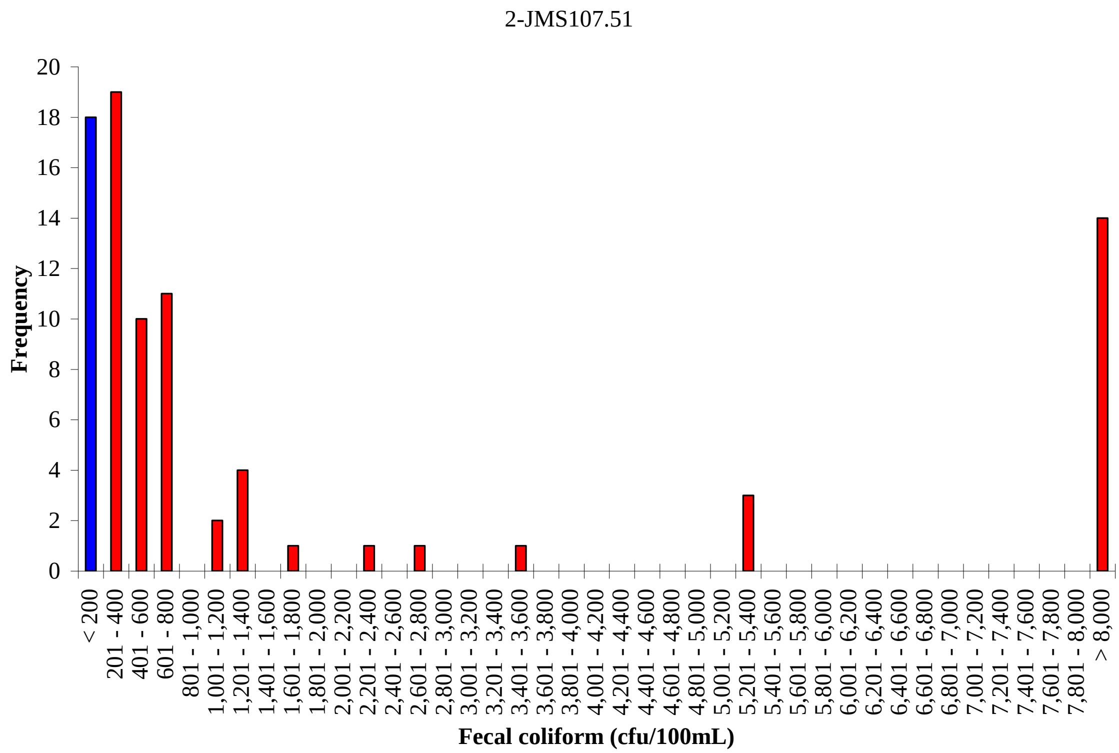

Figure A. 27 Frequency analysis of fecal coliform concentrations at station 2-JMS107.51 in the James River impairment from 6/94 to 8/01.

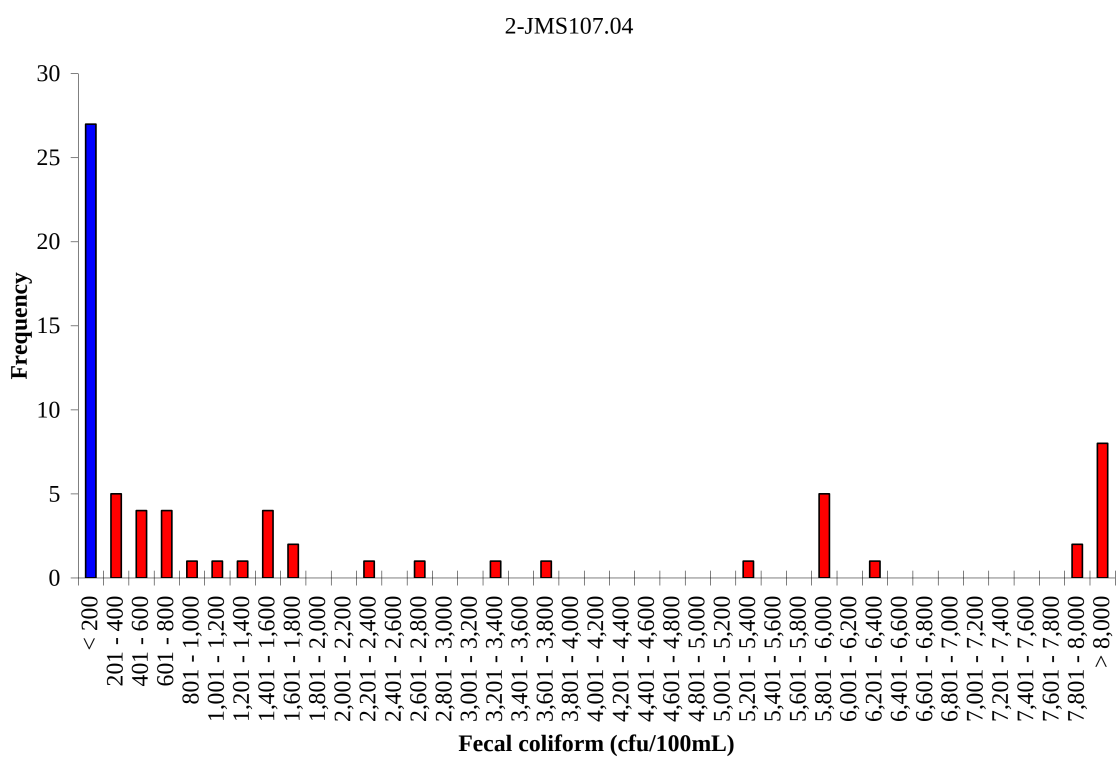

Figure A. 28 Frequency analysis of fecal coliform concentrations at station 2-JMS107.04 in the James River impairment from 5/80 to 9/83.

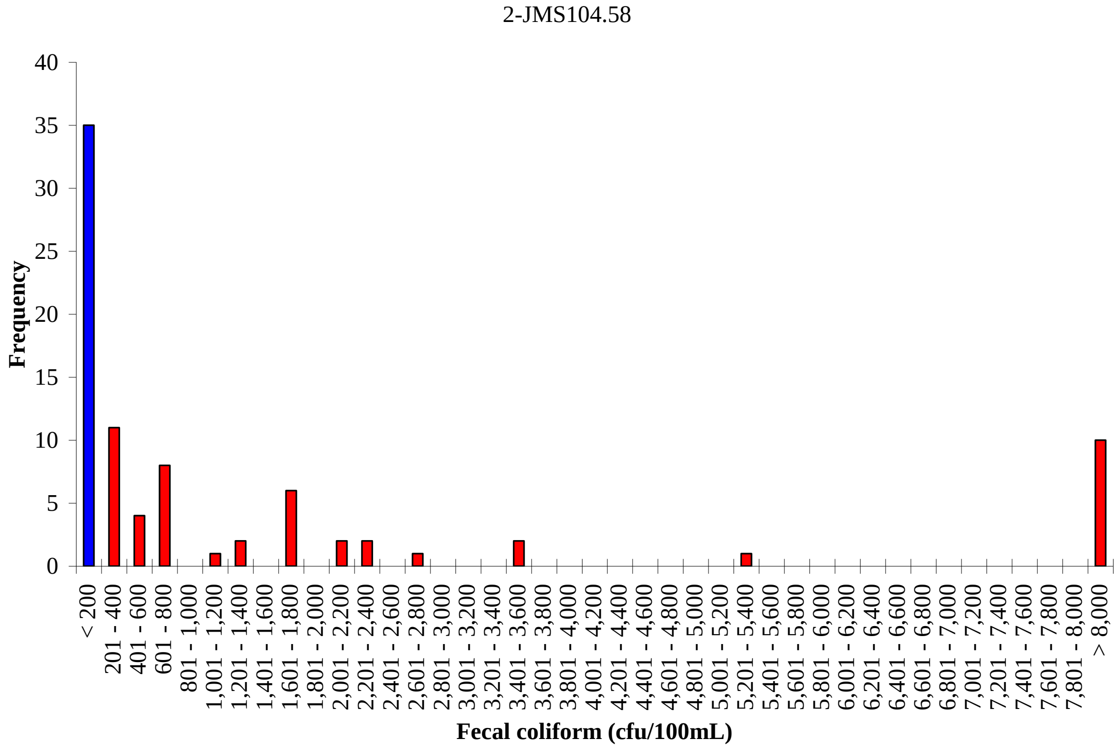

Figure A. 29 Frequency analysis of fecal coliform concentrations at station 2-JMS104.58 in the James River impairment from 6/94 to 8/01.

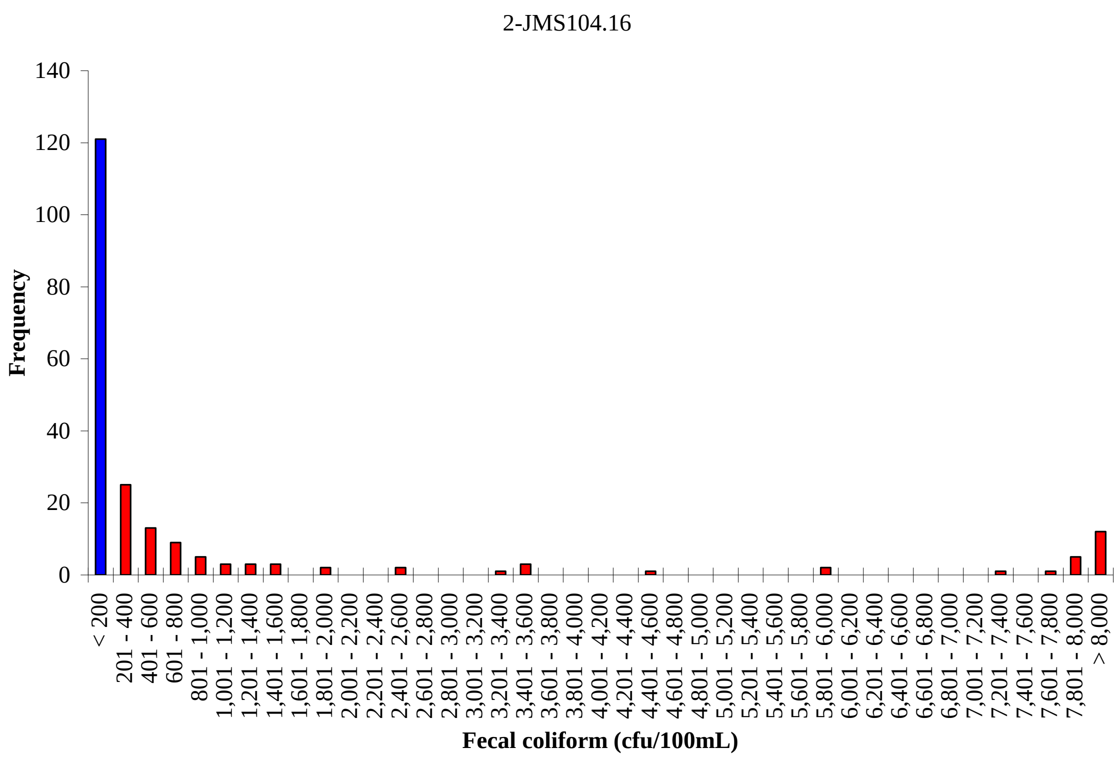

Figure A. 30 Frequency analysis of fecal coliform concentrations at station 2-JMS104.16 in the James River impairment from 5/80 to 1/06.

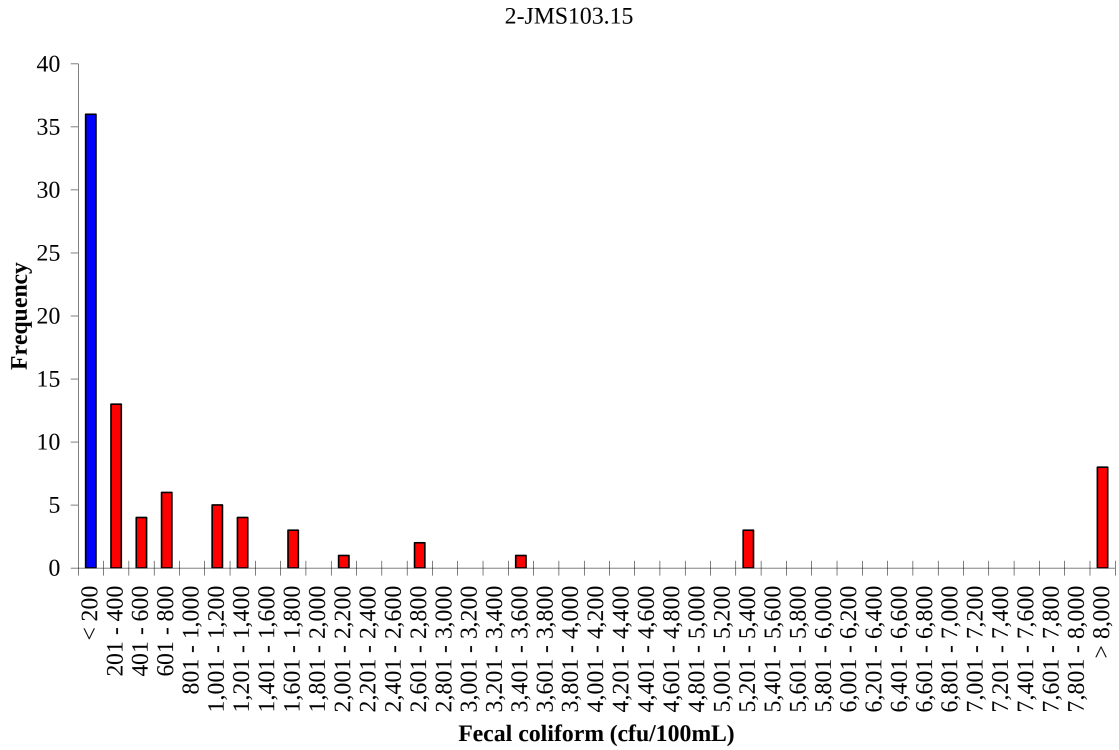

Figure A. 31 Frequency analysis of fecal coliform concentrations at station 2-JMS103.15 in the James River impairment from 9/83 to 8/01.

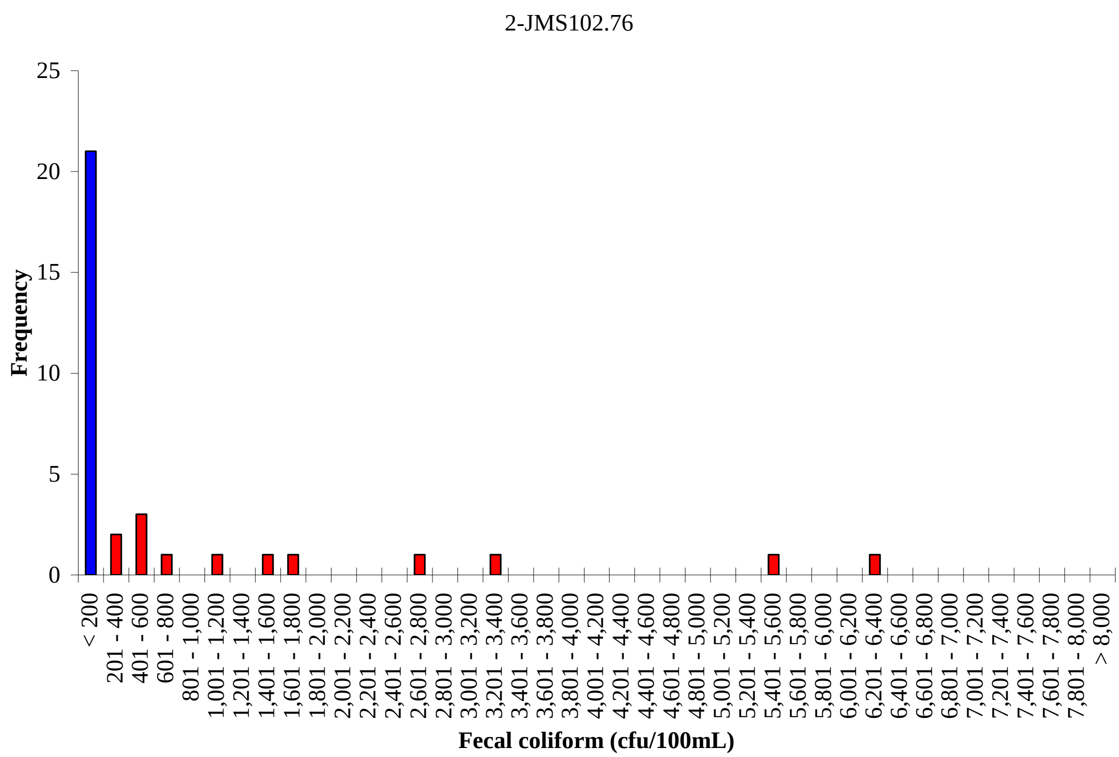

Figure A. 32 Frequency analysis of fecal coliform concentrations at station 2-JMS102.76 in the James River impairment from 5/80 to 9/83.

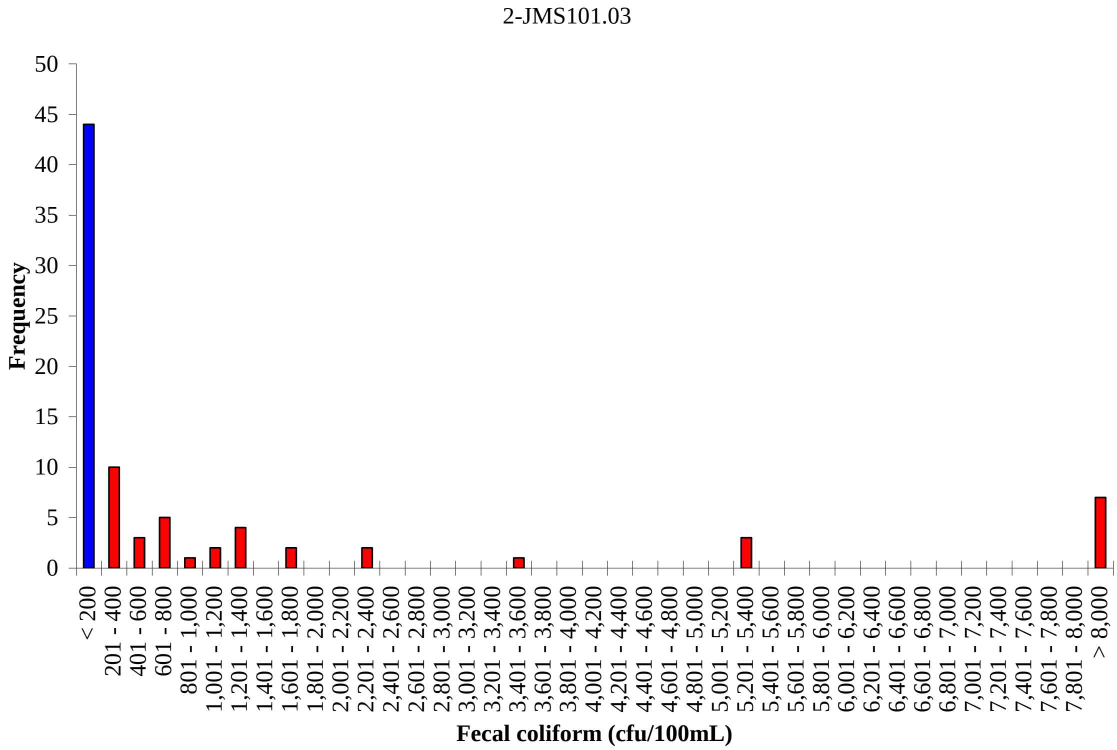

Figure A. 33 Frequency analysis of fecal coliform concentrations at station 2-JMS101.03 in the James River impairment from 7/94 to 8/01.

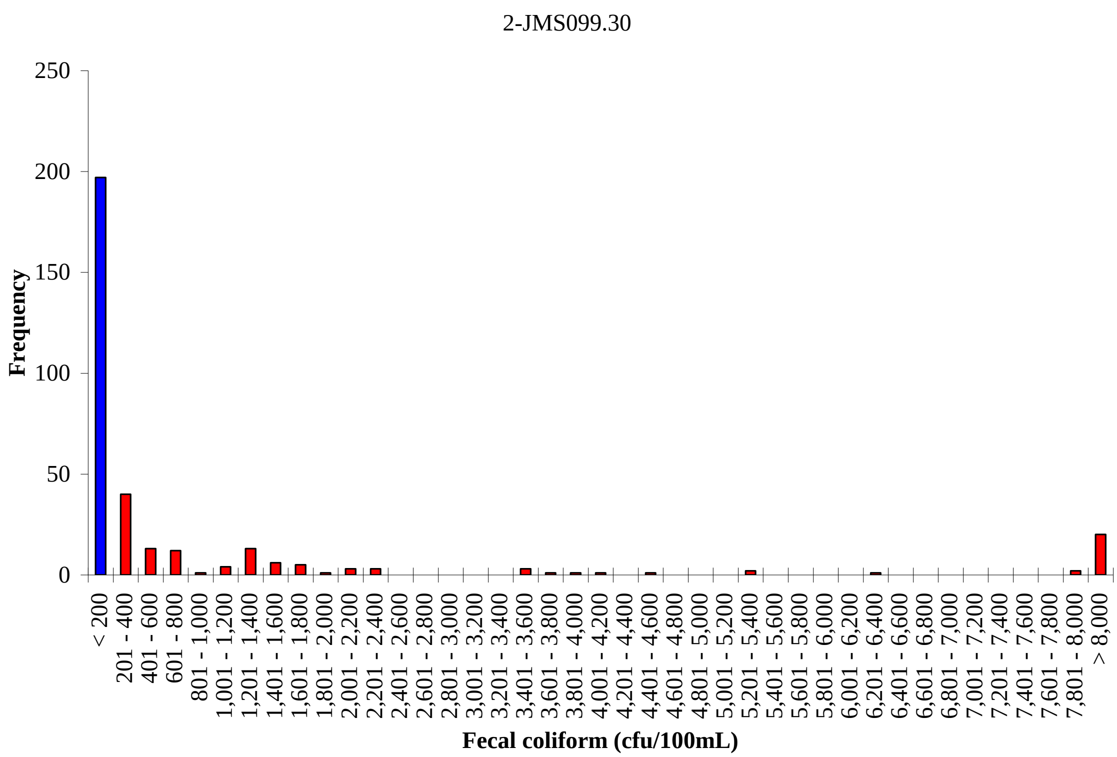

Figure A. 34 Frequency analysis of fecal coliform concentrations at station 2-JMS099.30 in the James River impairment from 5/80 to 1/06.

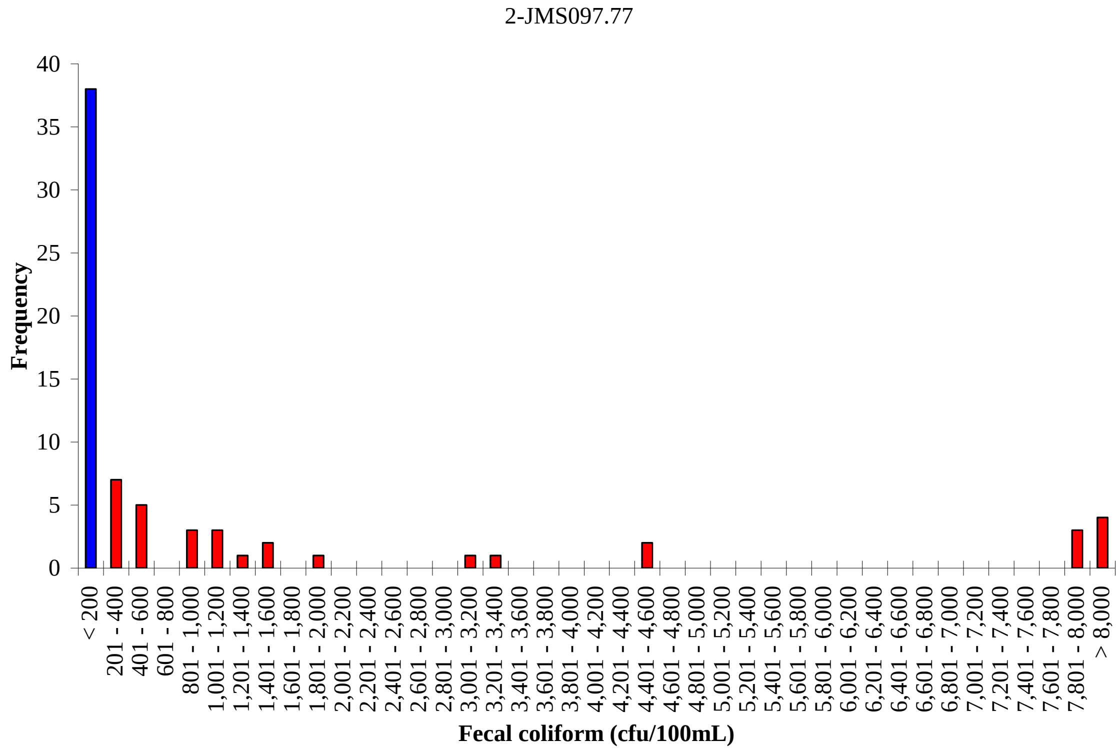

Figure A. 35 Frequency analysis of fecal coliform concentrations at station 2-JMS097.77 in the James River impairment from 4/70 to 9/83.

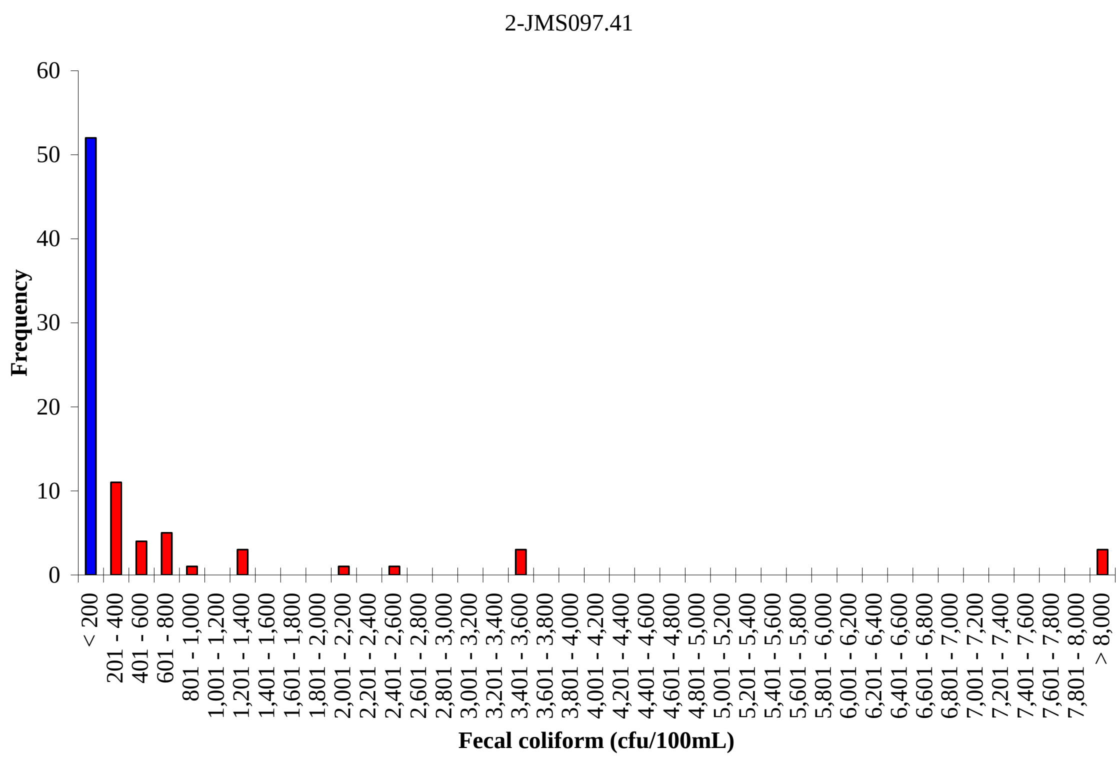

Figure A. 36 Frequency analysis of fecal coliform concentrations at station 2-JMS097.41 in the James River impairment from 7/94 to 8/01.

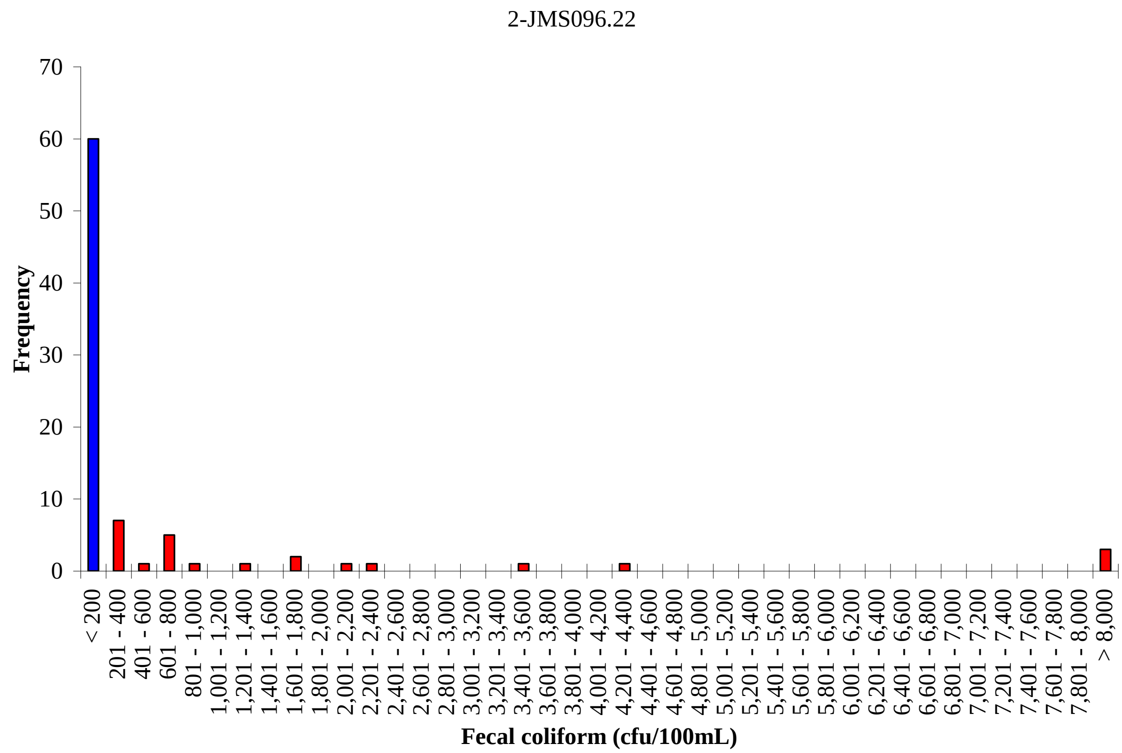

Figure A. 37 Frequency analysis of fecal coliform concentrations at station 2-JMS096.22 in the James River impairment from 7/94 to 8/01.

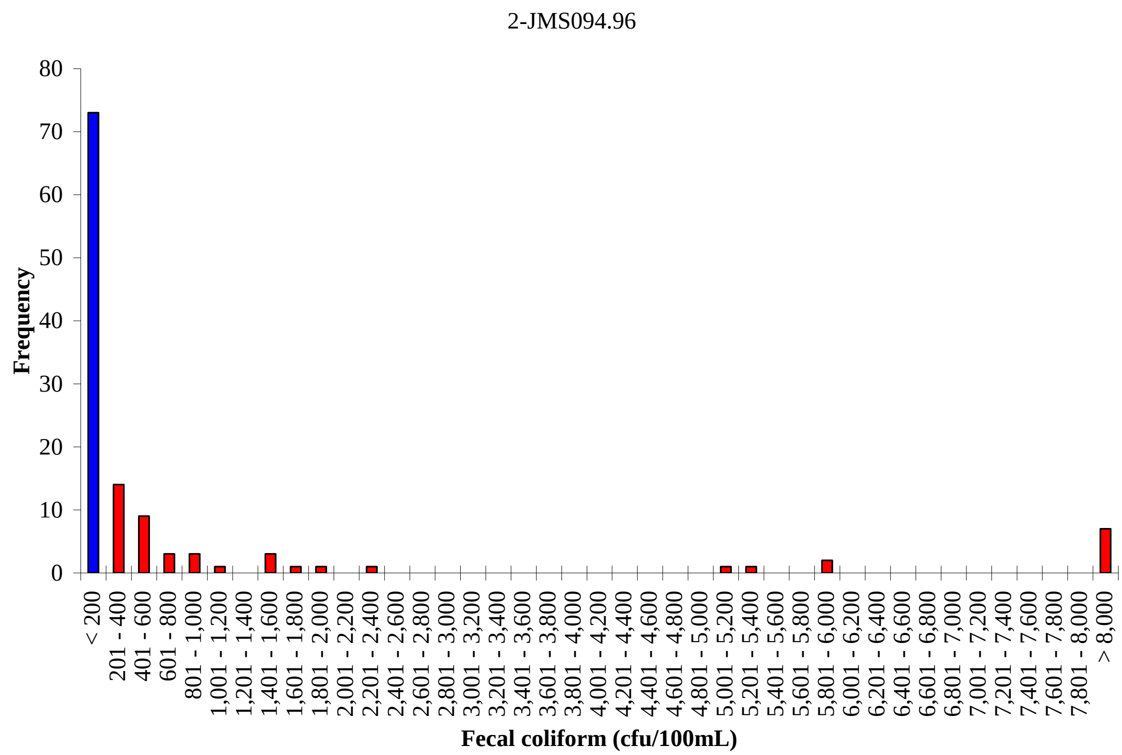

Figure A. 38 Frequency analysis of fecal coliform concentrations at station 2-JMS094.96 in the James River impairment from 4/70 to 8/01.

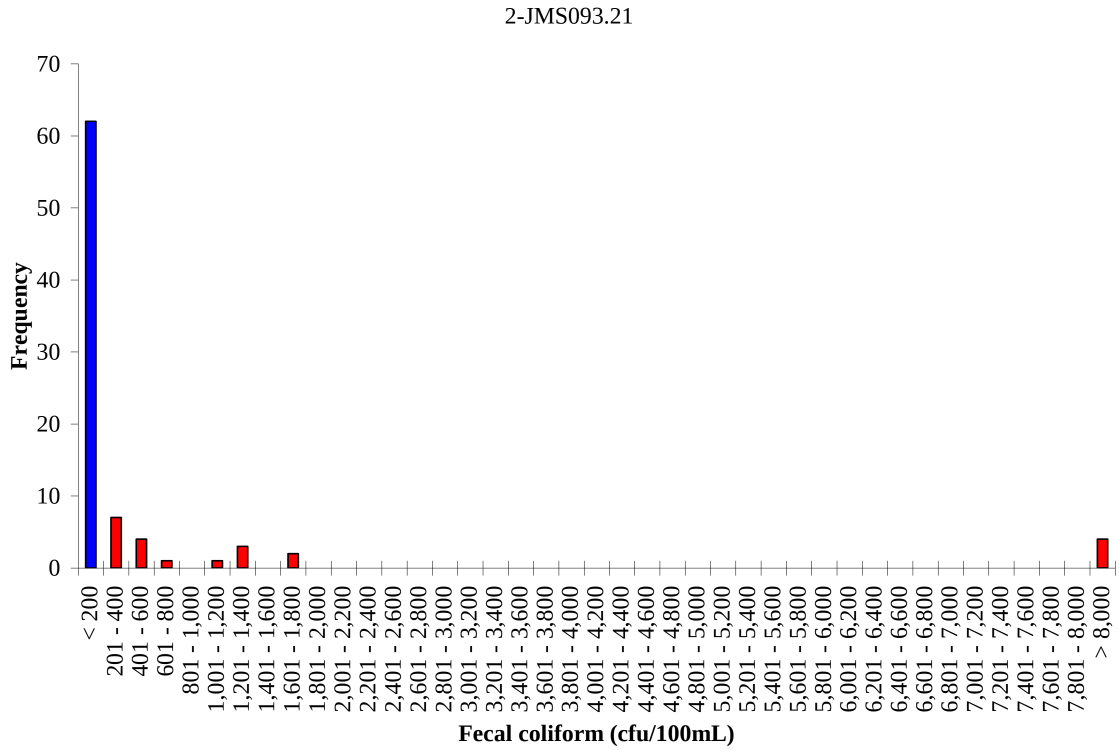

Figure A. 39 Frequency analysis of fecal coliform concentrations at station 2-JMS093.21 in the James River impairment from 7/94 to 8/01.

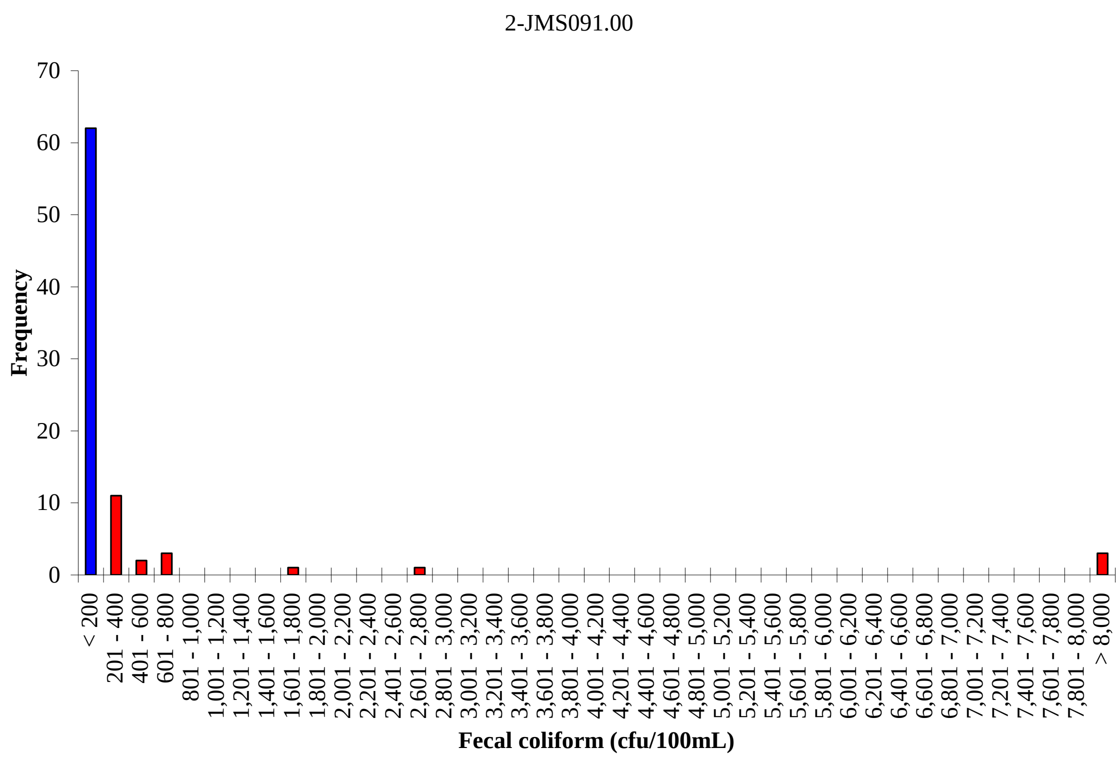

Figure A. 40 Frequency analysis of fecal coliform concentrations at station 2-JMS091.00 in the James River impairment from 7/94 to 8/01.

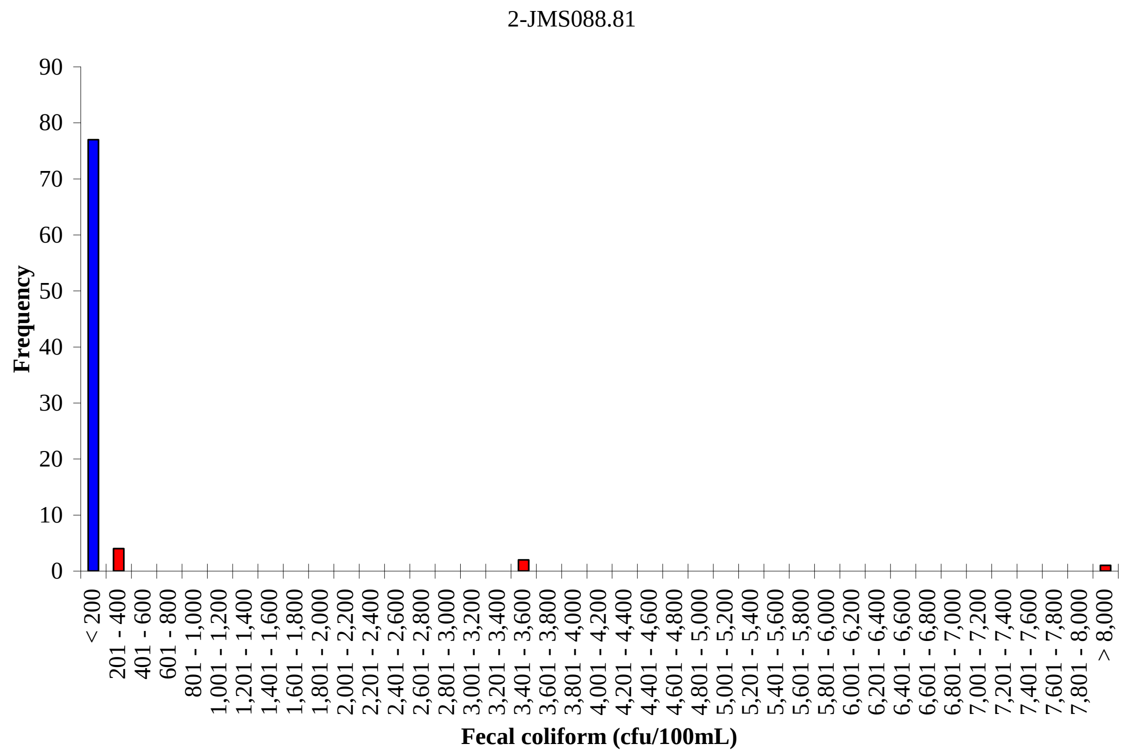

Figure A. 41 Frequency analysis of fecal coliform concentrations at station 2-JMS088.81 in the James River impairment from 7/94 to 8/01.

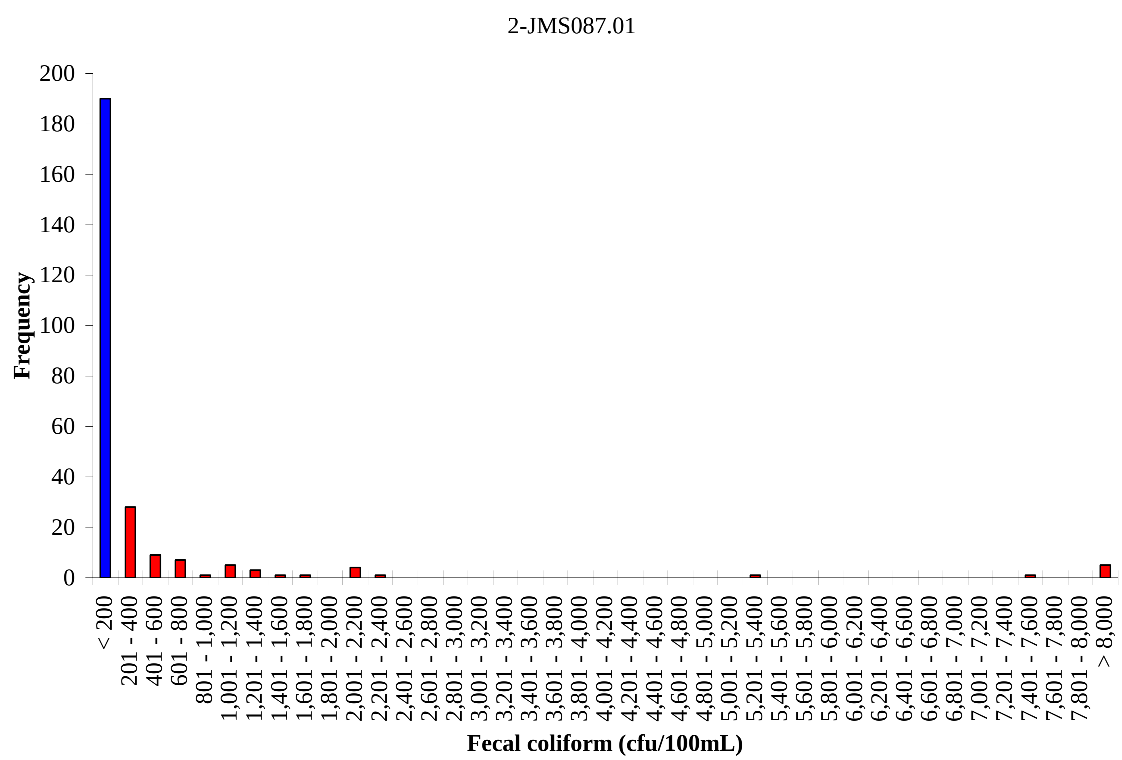

Figure A. 42 Frequency analysis of fecal coliform concentrations at station 2-JMS087.01 in the James River impairment from 5/74 to 1/06.

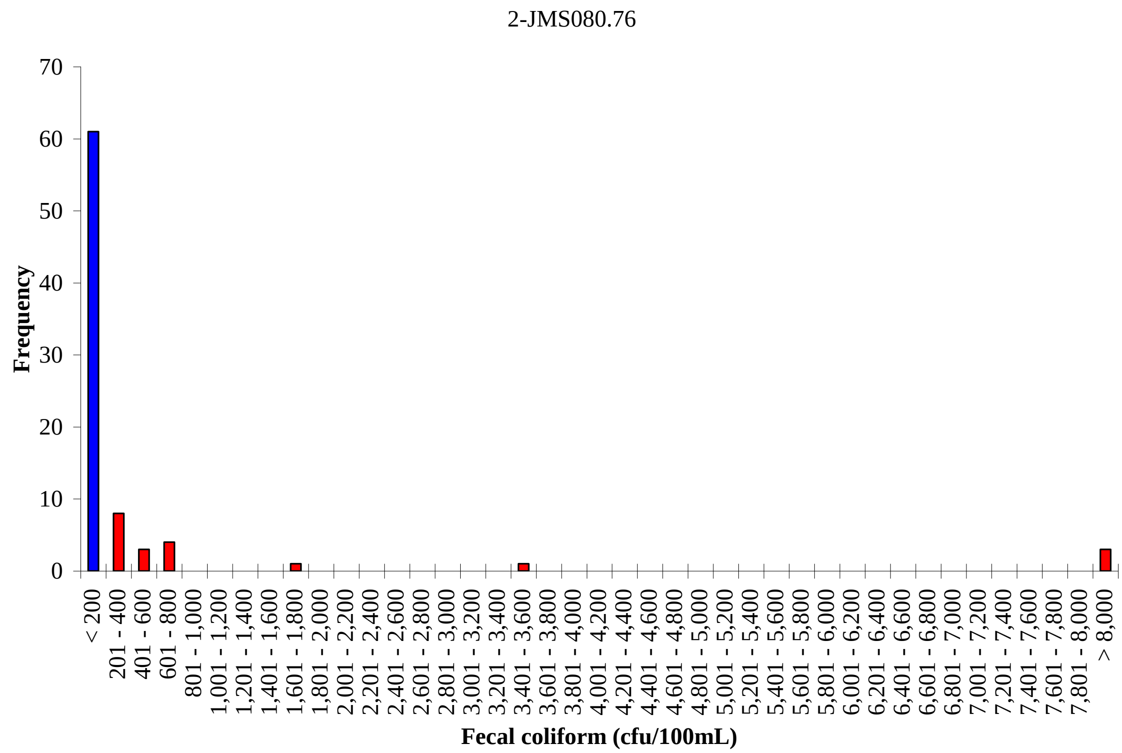

Figure A. 43 Frequency analysis of fecal coliform concentrations at station 2-JMS080.76 in the James River impairment from 7/94 to 8/01.

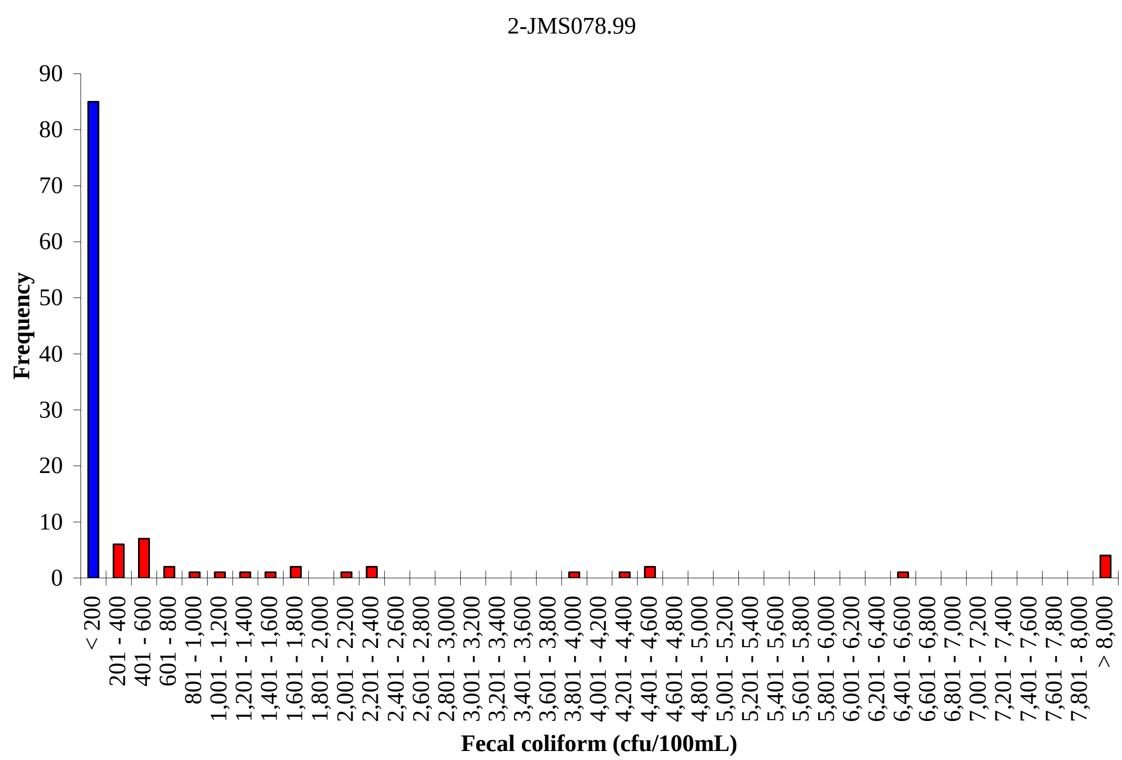

Figure A. 44 Frequency analysis of fecal coliform concentrations at station 2-JMS078.99 in the James River impairment from 4/70 to 8/01.

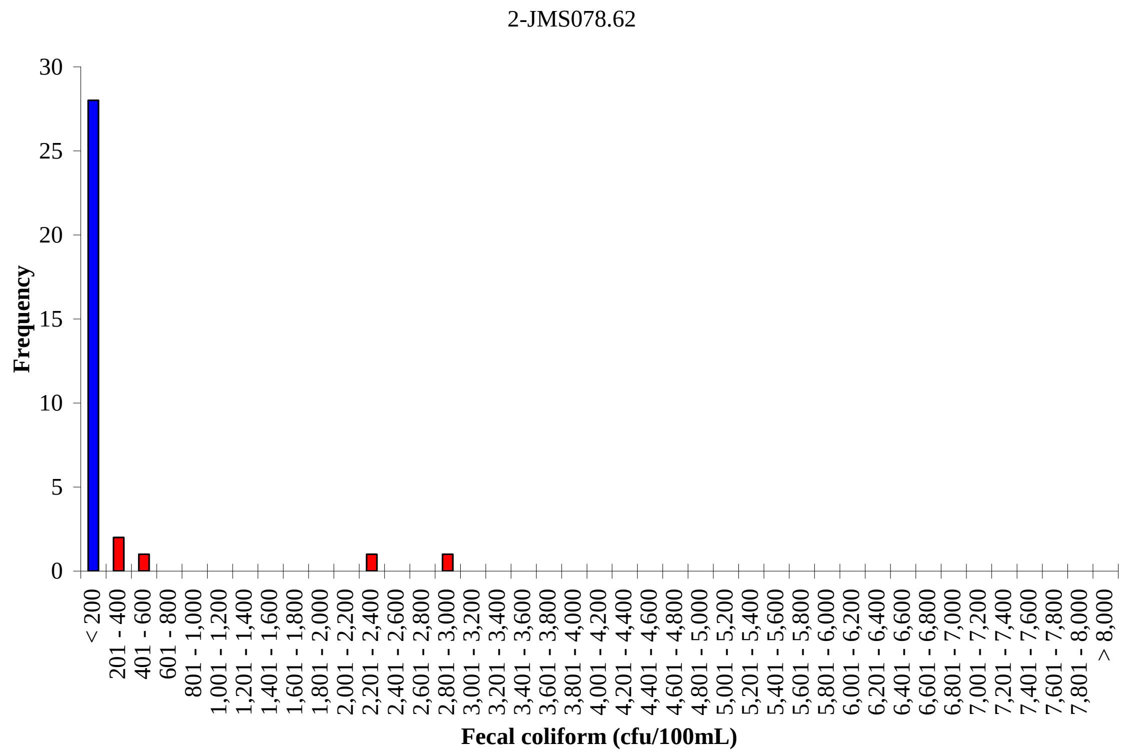

Figure A. 45 Frequency analysis of fecal coliform concentrations at station 2-JMS078.62 in the James River impairment from 5/75 to 6/83.

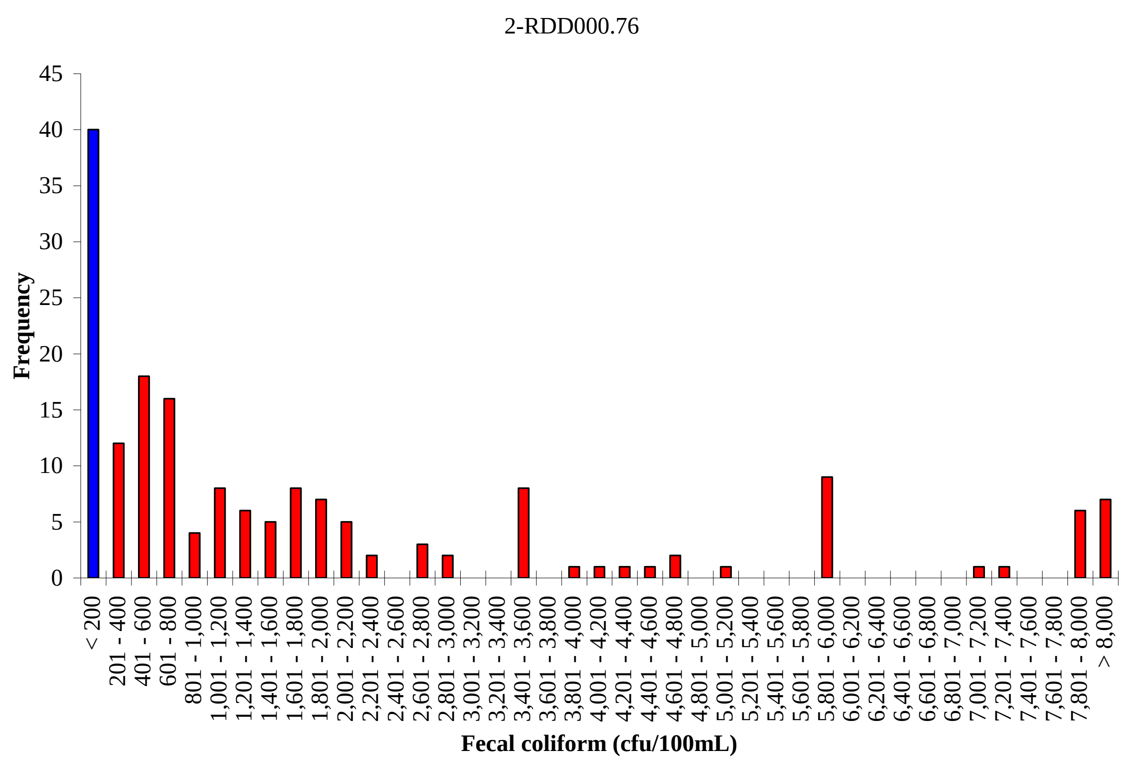

Figure A. 46 Frequency analysis of fecal coliform concentrations at station 2-RDD000.76 in the Reedy Creek impairment from 2/80 to 6/90.

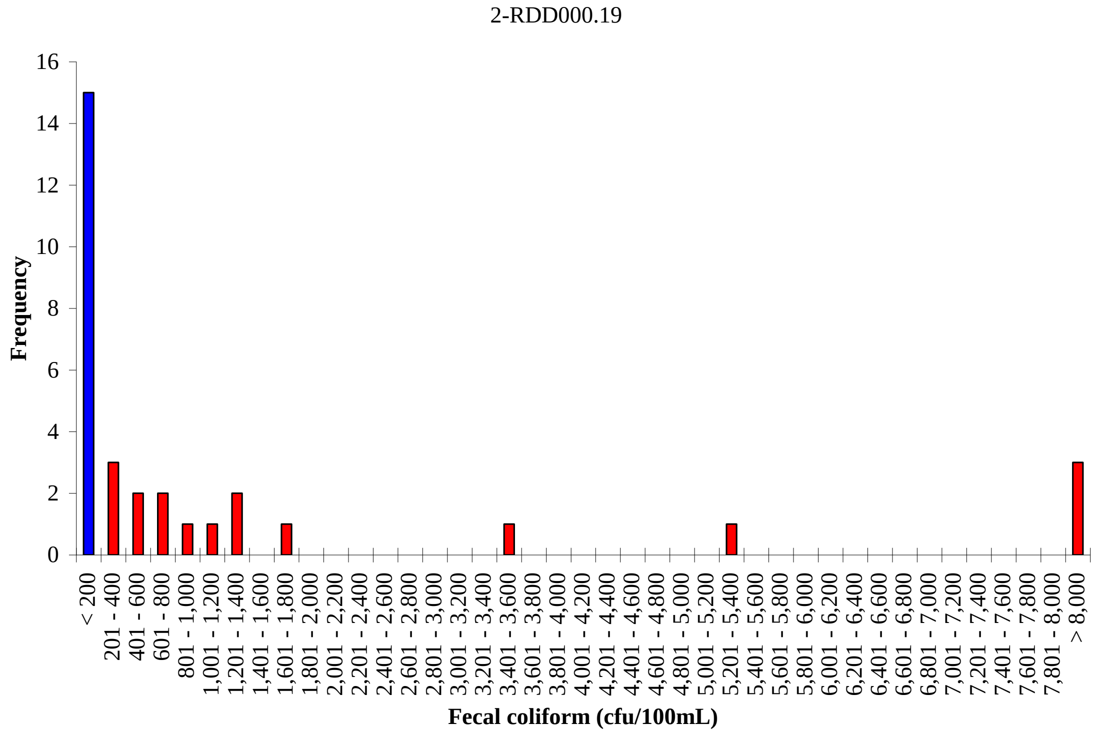

Figure A. 47 Frequency analysis of fecal coliform concentrations at station 2-RDD000.19 in the Reedy Creek impairment from 7/94 to 1/01.

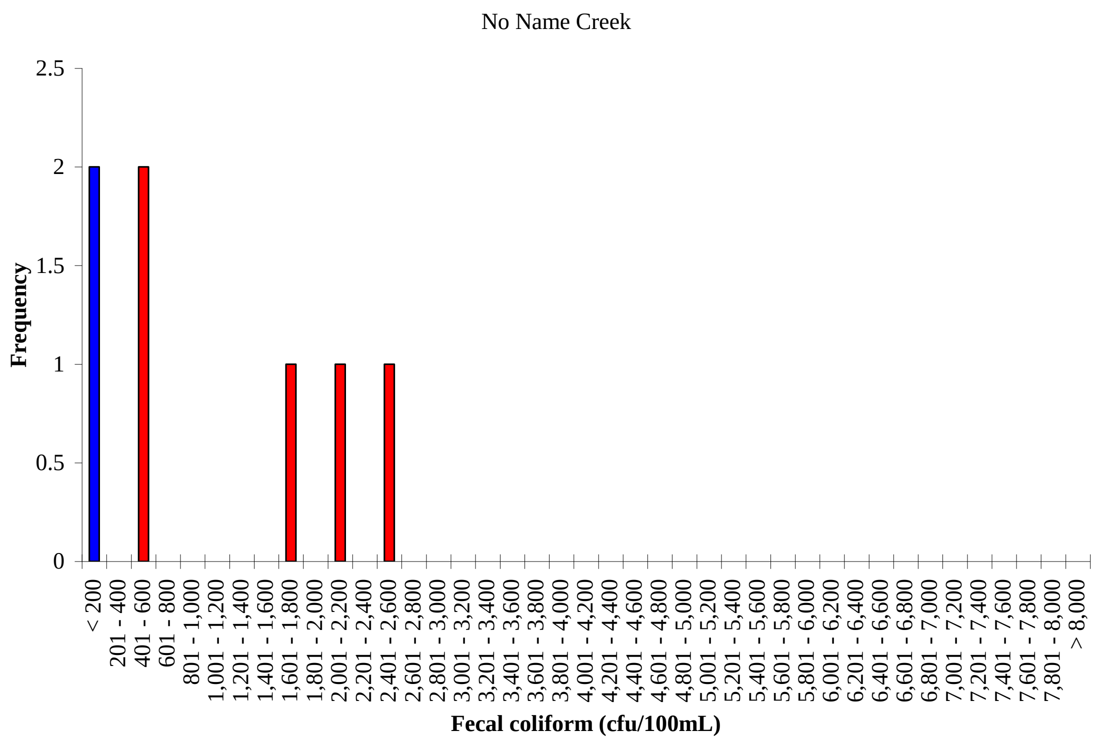

Figure A. 48 Frequency analysis of FC concentrations at stations 2-XSZ002.24, 2-XVL000.04, 2-XUI000.01, 2-XUH000.01, 2-XTC000.08 in the No Name Creek impairment from 3/02 to 10/02.

APPENDIX B: CONCENTRATION VERSUS DURATION GRAPHS BY WATER QUALITY MONITORING STATION

Trend and Seasonal Analyses

Box and whisker Plots

Concentration versus Duration Graphs

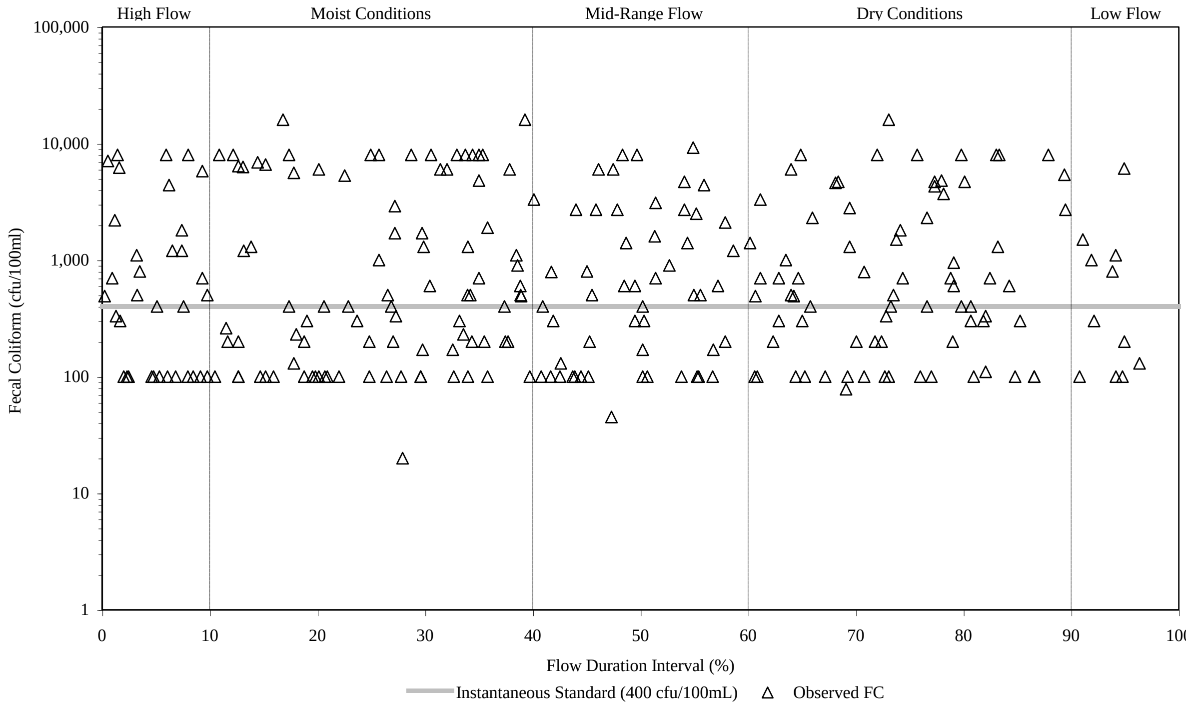

Figure B.1 Fecal coliform concentrations at 2-ALM000.42 in Almond Creek versus discharge at USGS Gaging Station #02037500.

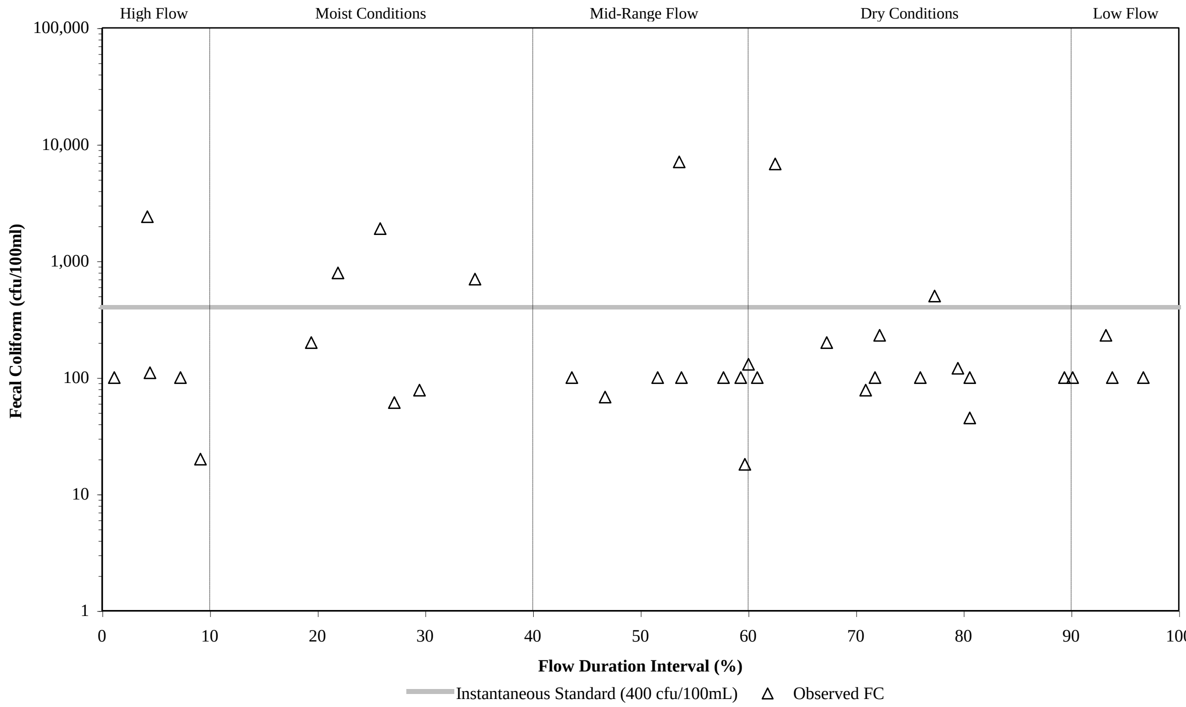

Figure B.2 Fecal coliform concentrations at 2-BOR001.73 in Bernards Creek versus discharge at USGS Gaging Station #02037500.

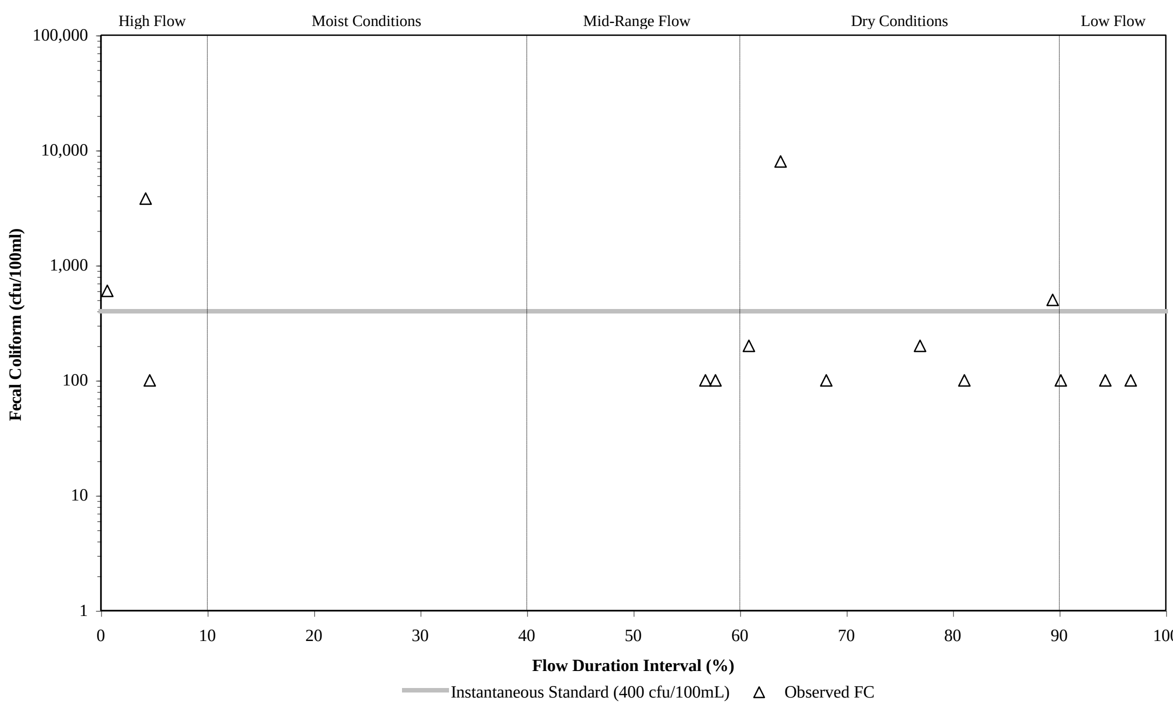

Figure B.3 Fecal coliform concentrations at 2-DPR001.00 in Deep Run versus discharge at USGS Gaging Station #02037500.

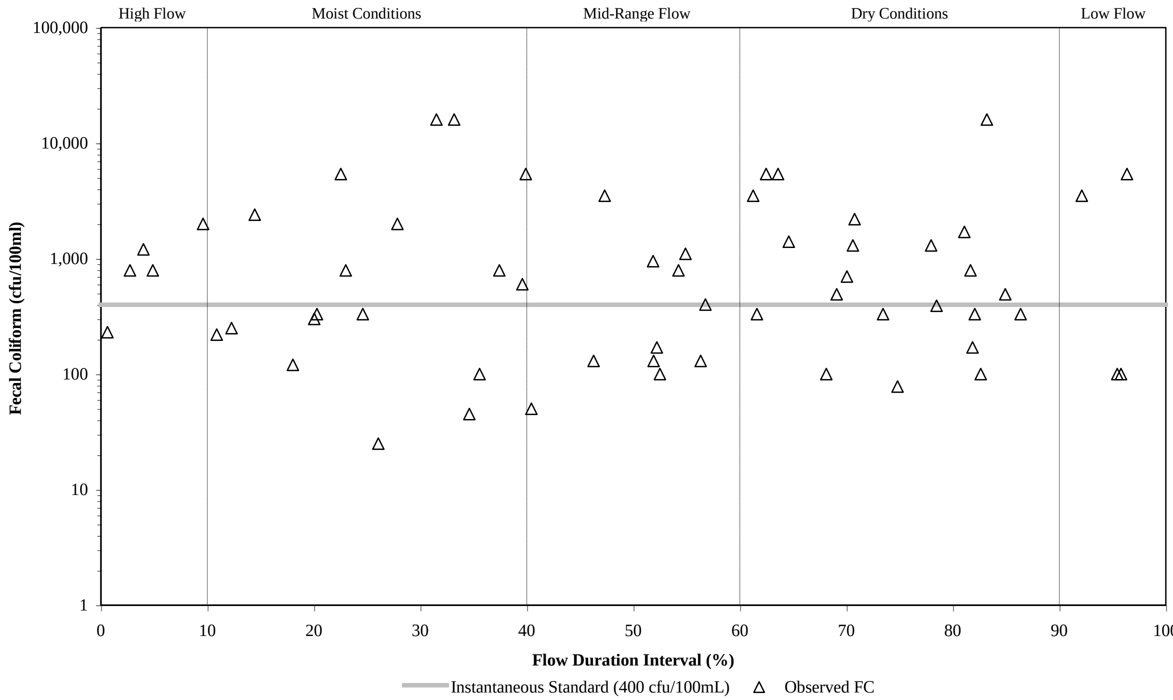

Figure B.4 Fecal coliform concentrations at 2-DPR002.46 in Deep Run versus discharge at USGS Gaging Station #02037500.

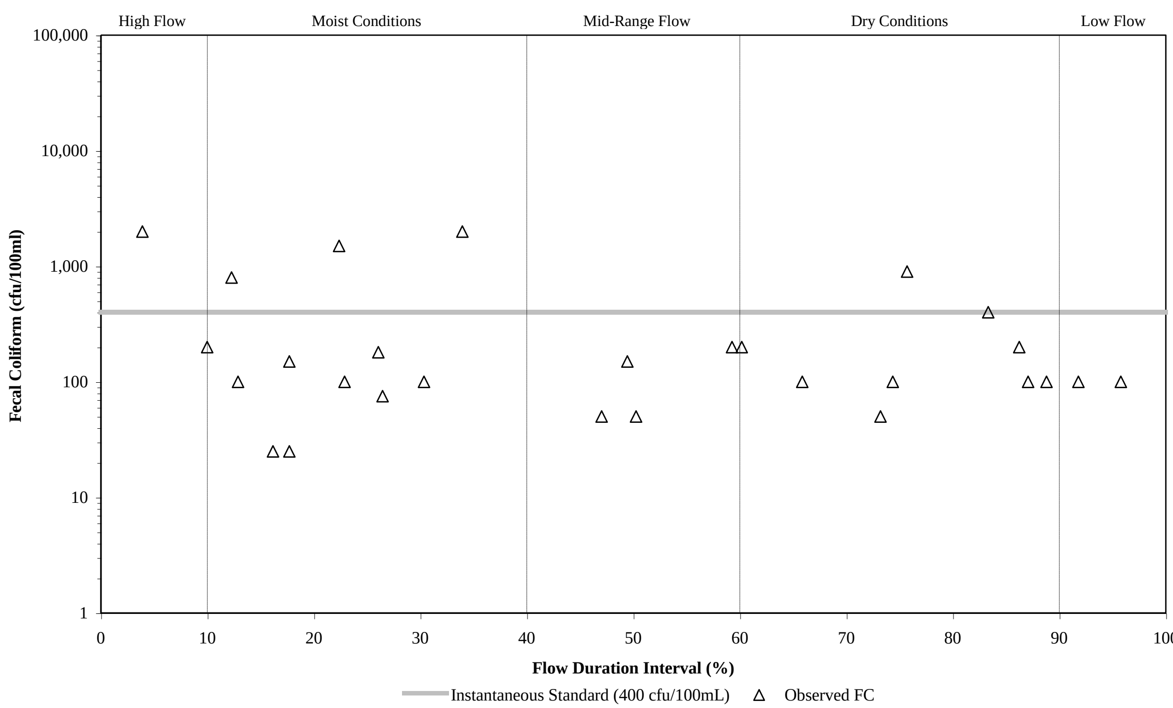

Figure B.5 Fecal coliform concentrations at 2-FAC009.46 in Falling Creek versus discharge at USGS Gaging Station #02037500.

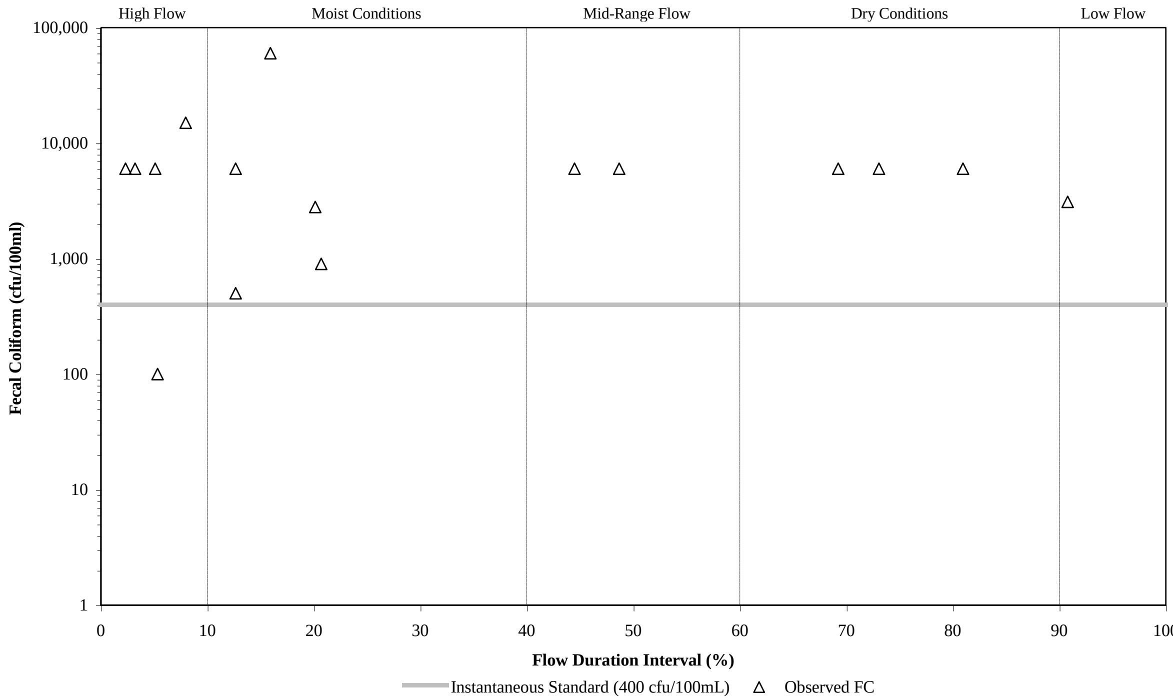

Figure B.6 Fecal coliform concentrations at 2-GIL000.03 in Gillie Creek versus discharge at USGS Gaging Station #02037500.

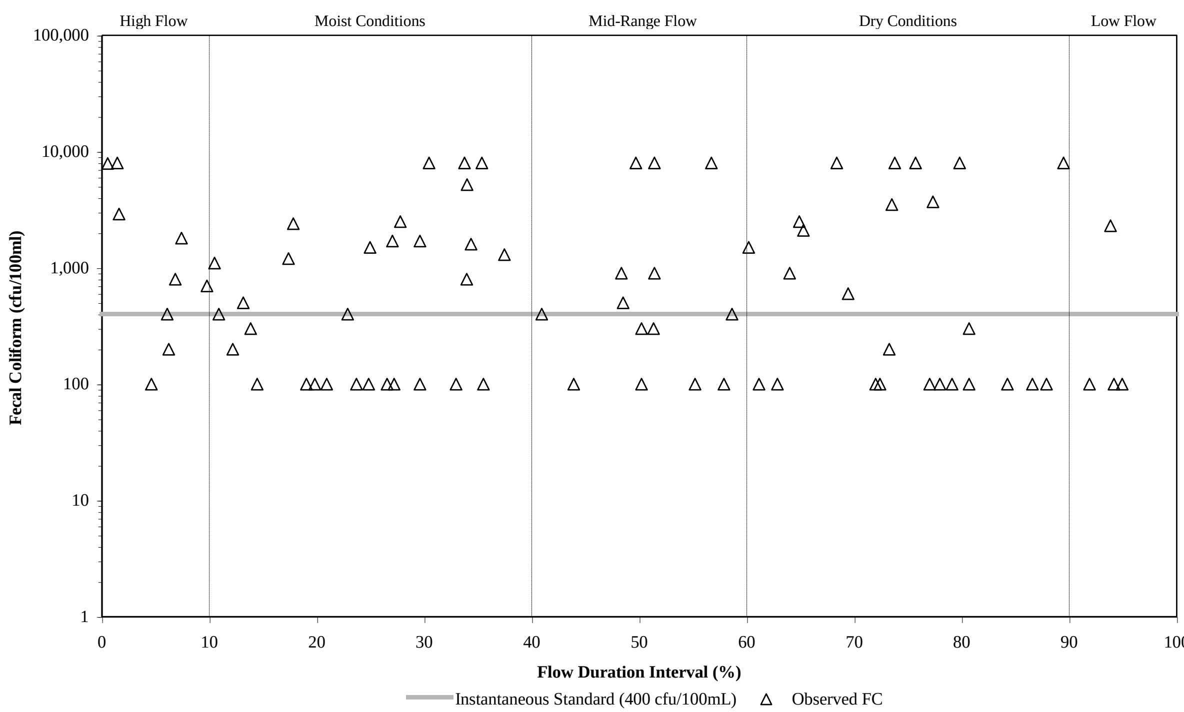

Figure B.7 Fecal coliform concentrations at 2-GIL000.42 in Gillie Creek versus discharge at USGS Gaging Station #02037500.R

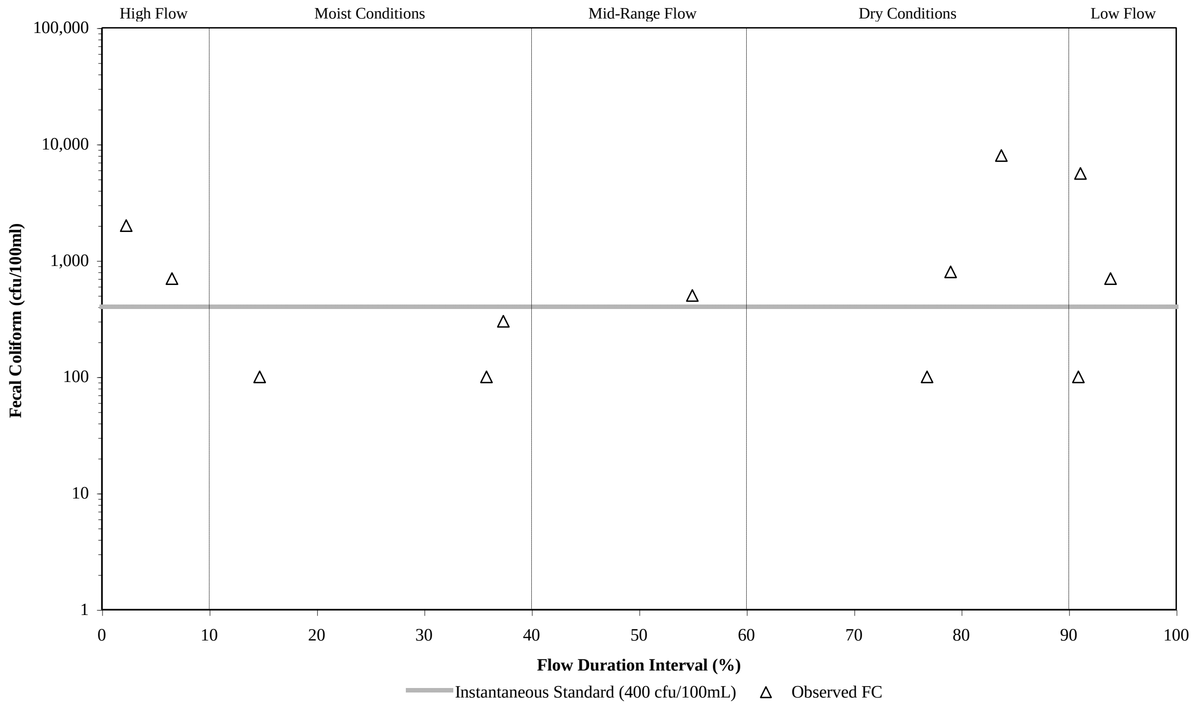

Figure B.8 Fecal coliform concentrations at 2-GIL001.00 in Gillie Creek versus discharge at USGS Gaging Station #02037500.

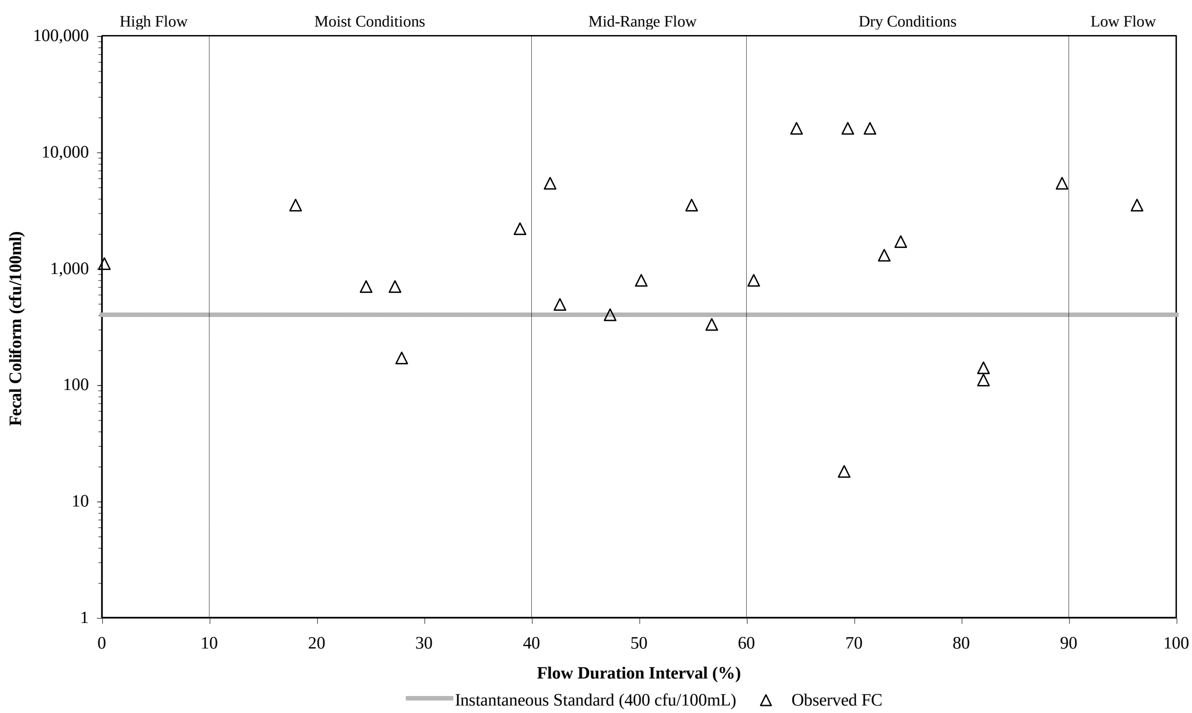

Figure B.9 Fecal coliform concentrations at 2-GOD000.77 in Goode Creek versus discharge at USGS Gaging Station #02037500.

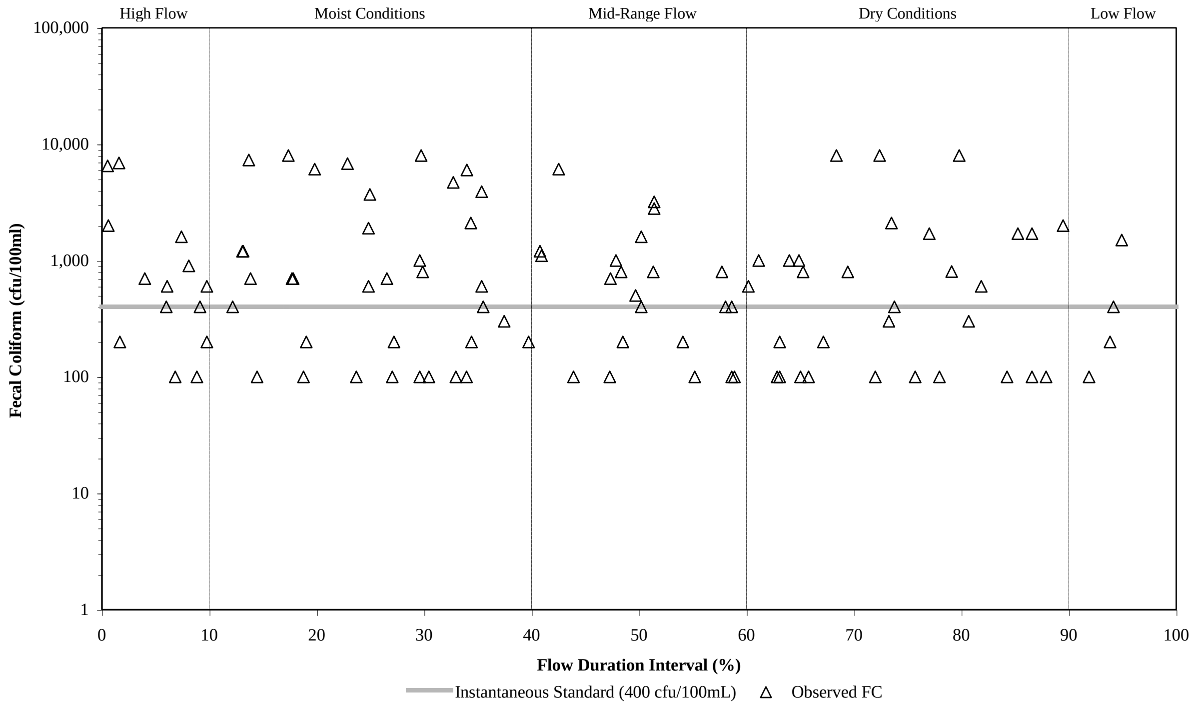

Figure B.10 Fecal coliform concentrations at 2-GRK000.57 in Grindall Creek versus discharge at USGS Gaging Station #02037500.

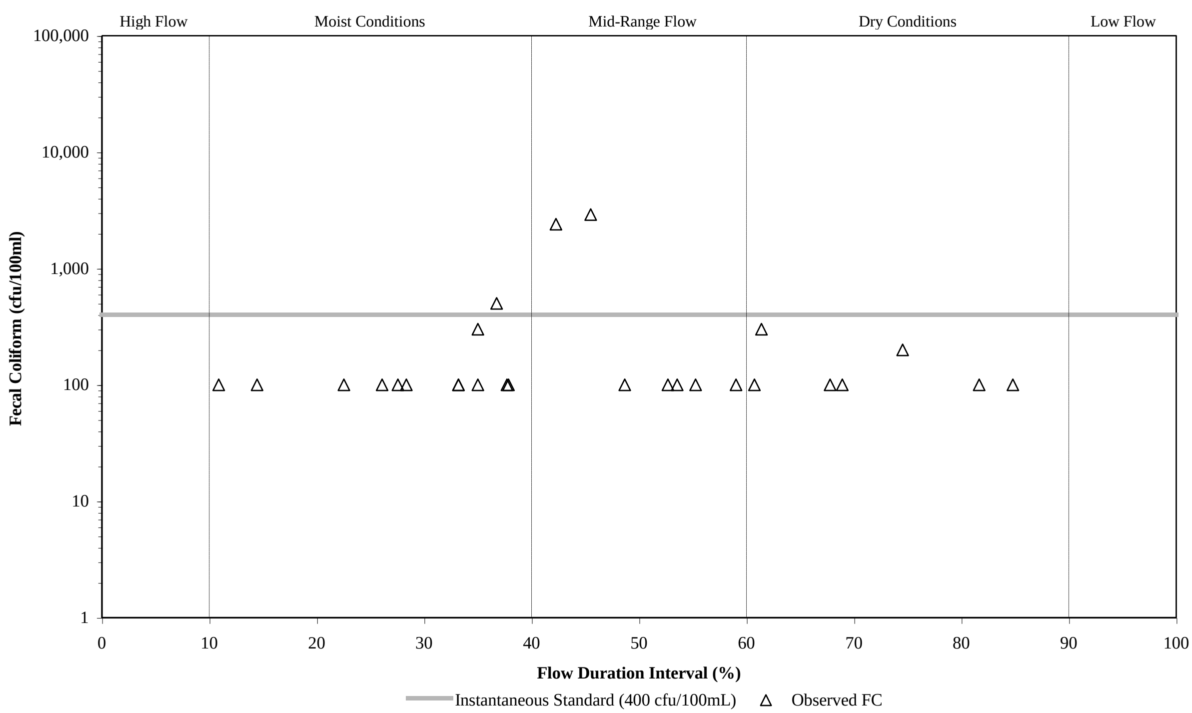

Figure B.11 Fecal coliform concentrations at 2-JMS078.62 in the James River versus discharge at USGS Gaging Station #02037500.

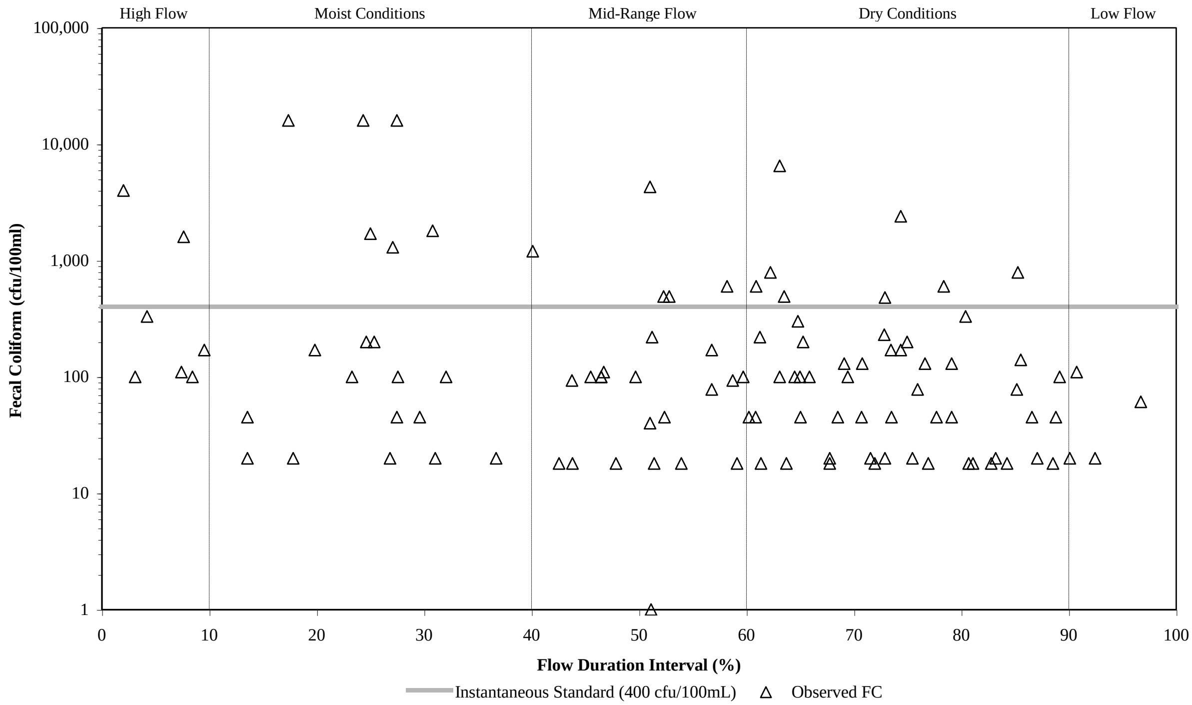

Figure B.12 Fecal coliform concentrations at 2-JMS078.99 in the James River versus discharge at USGS Gaging Station #02037500.

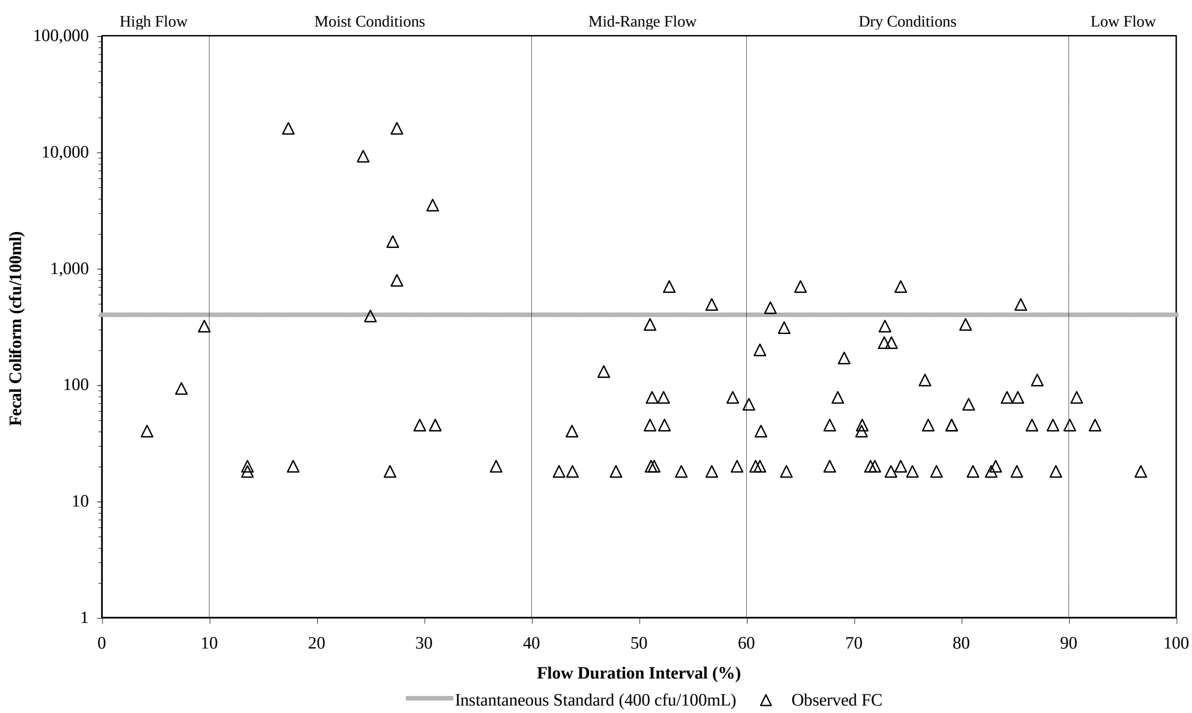

Figure B.13 Fecal coliform concentrations at 2-JMS080.76 in the James River versus discharge at USGS Gaging Station #02037500.

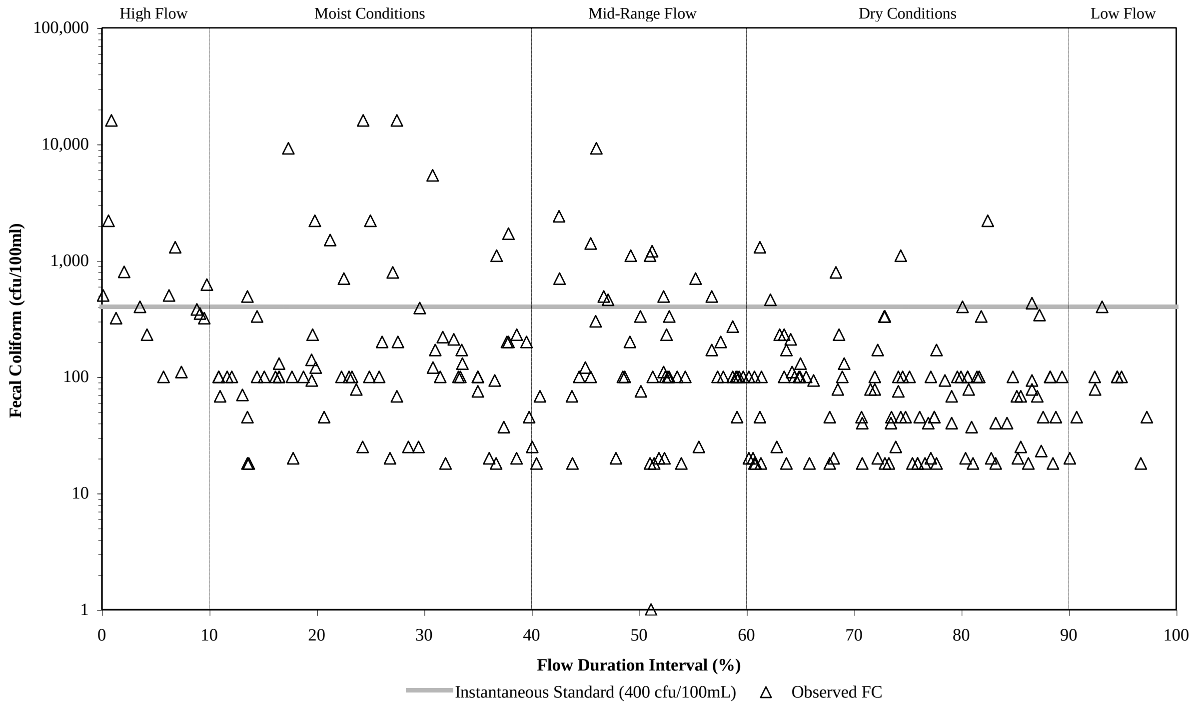

Figure B.14 Fecal coliform concentrations at 2-JMS087.01 in the James River versus discharge at USGS Gaging Station #02037500.

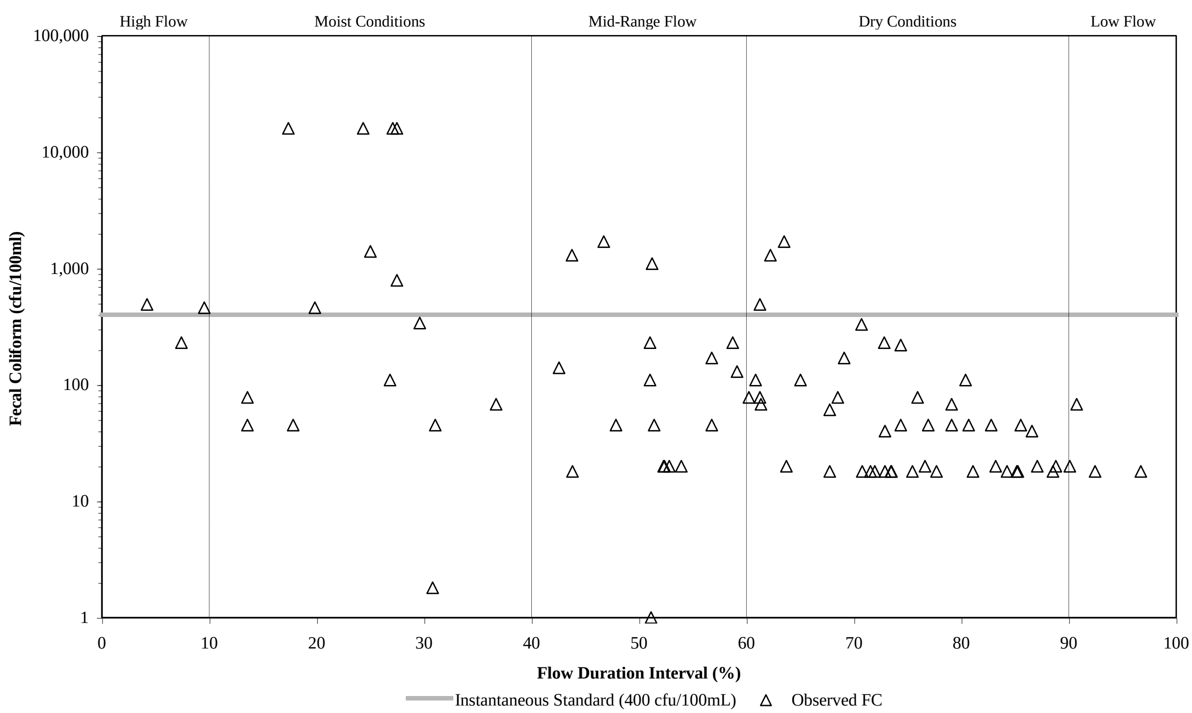

Figure B.15 Fecal coliform concentrations at 2-JMS093.21 in the James River versus discharge at USGS Gaging Station #02037500.

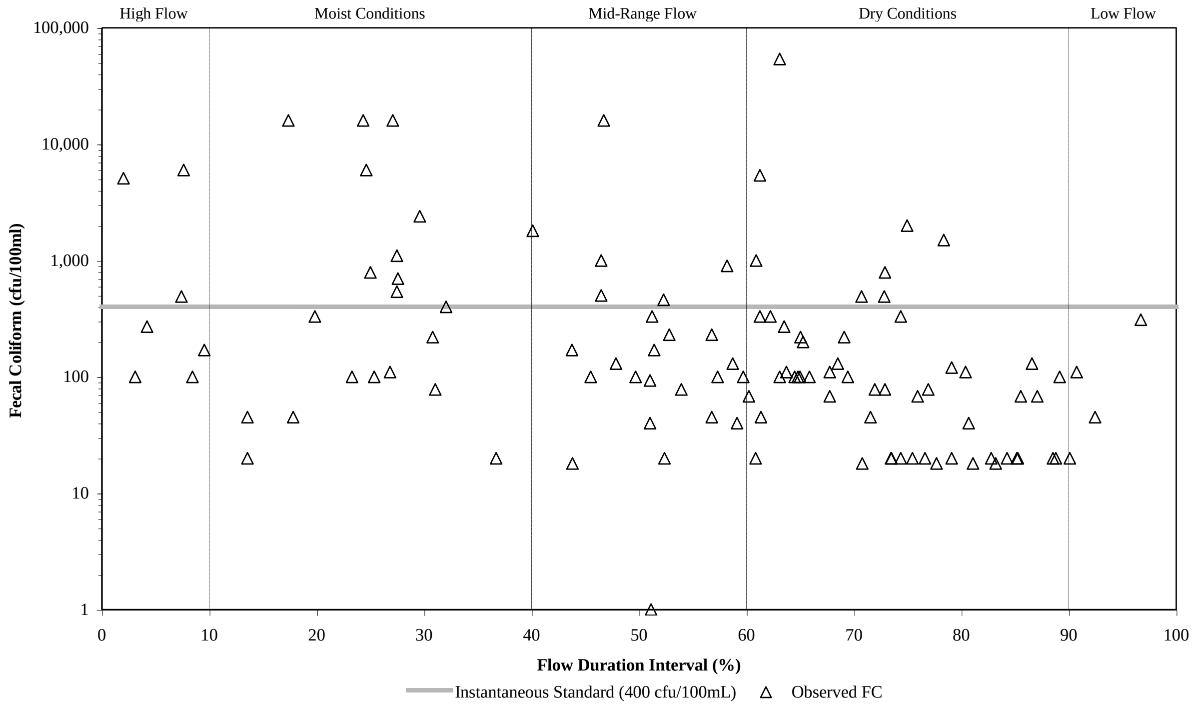

Figure B.16 Fecal coliform concentrations at 2-JMS094.96 in the James River versus discharge at USGS Gaging Station #02037500.

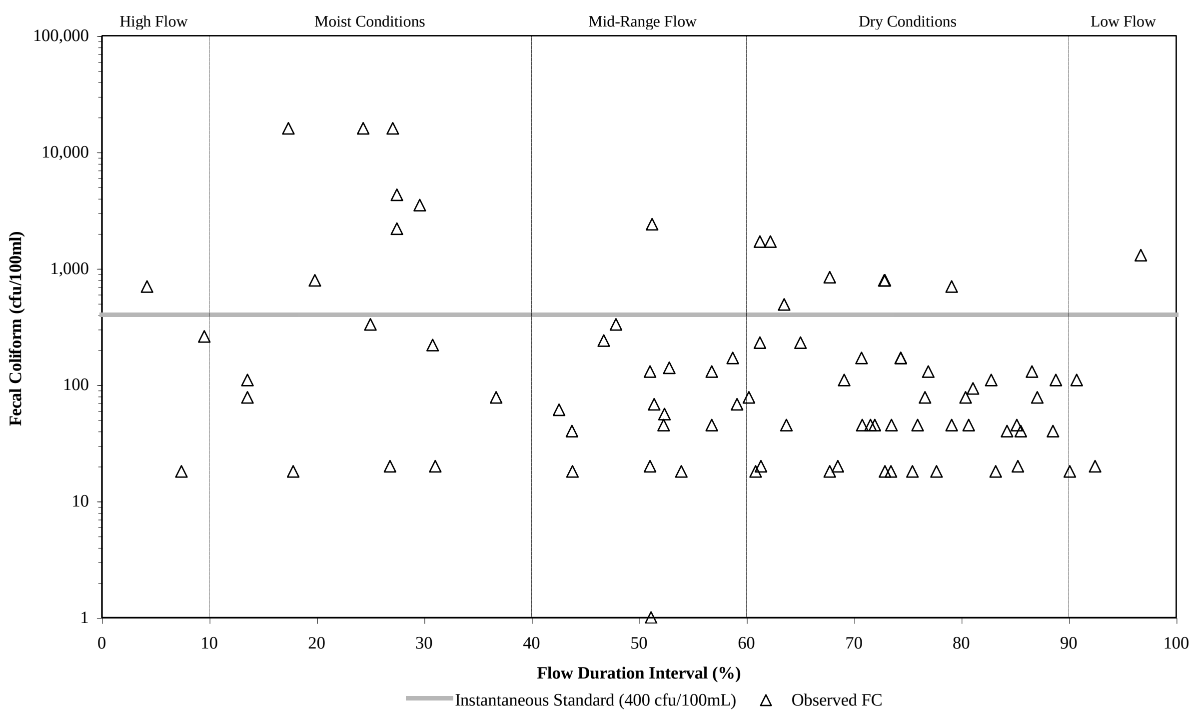

Figure B.17 Fecal coliform concentrations at 2-JMS096.22 in the James River versus discharge at USGS Gaging Station #02037500.

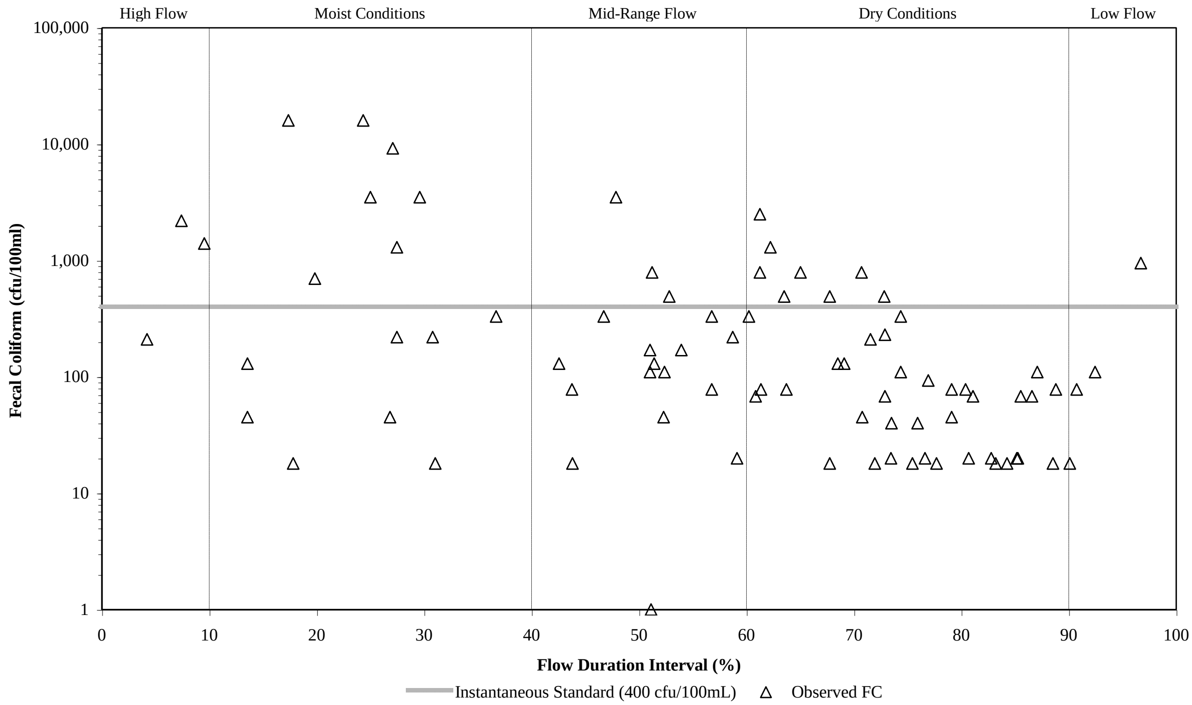

Figure B.18 Fecal coliform concentrations at 2-JMS097.41 in the James River versus discharge at USGS Gaging Station #02037500.

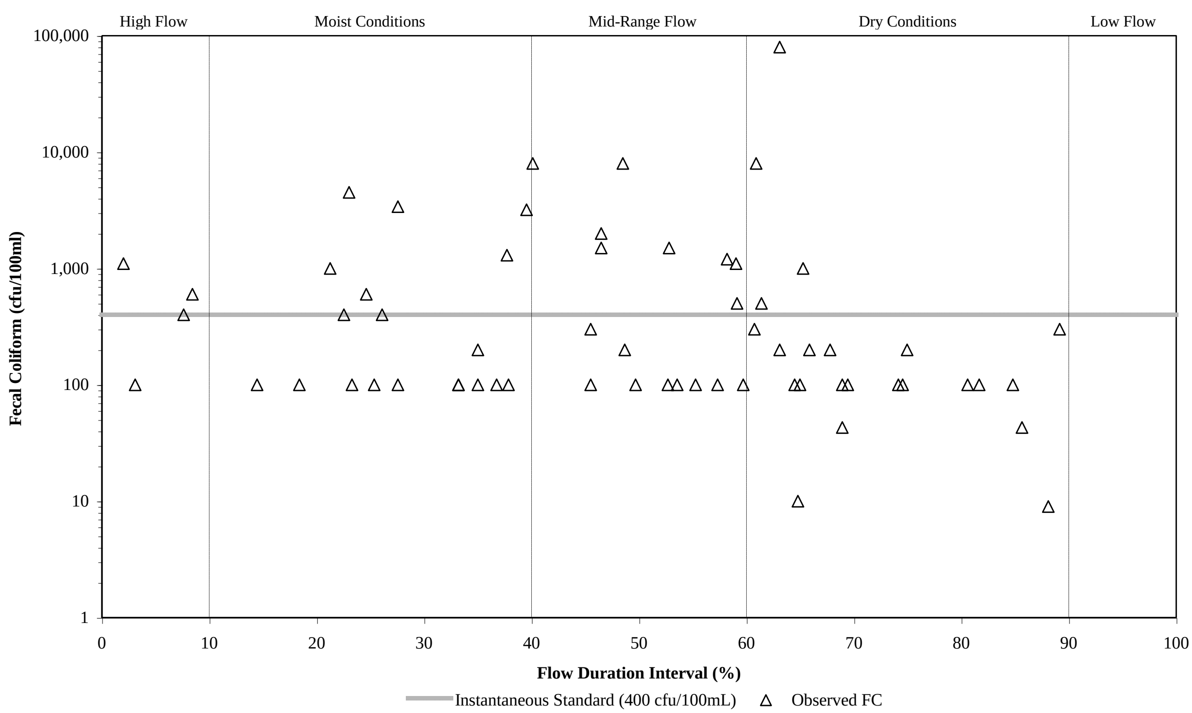

Figure B.19 Fecal coliform concentrations at 2-JMS097.77 in the James River versus discharge at USGS Gaging Station #02037500.

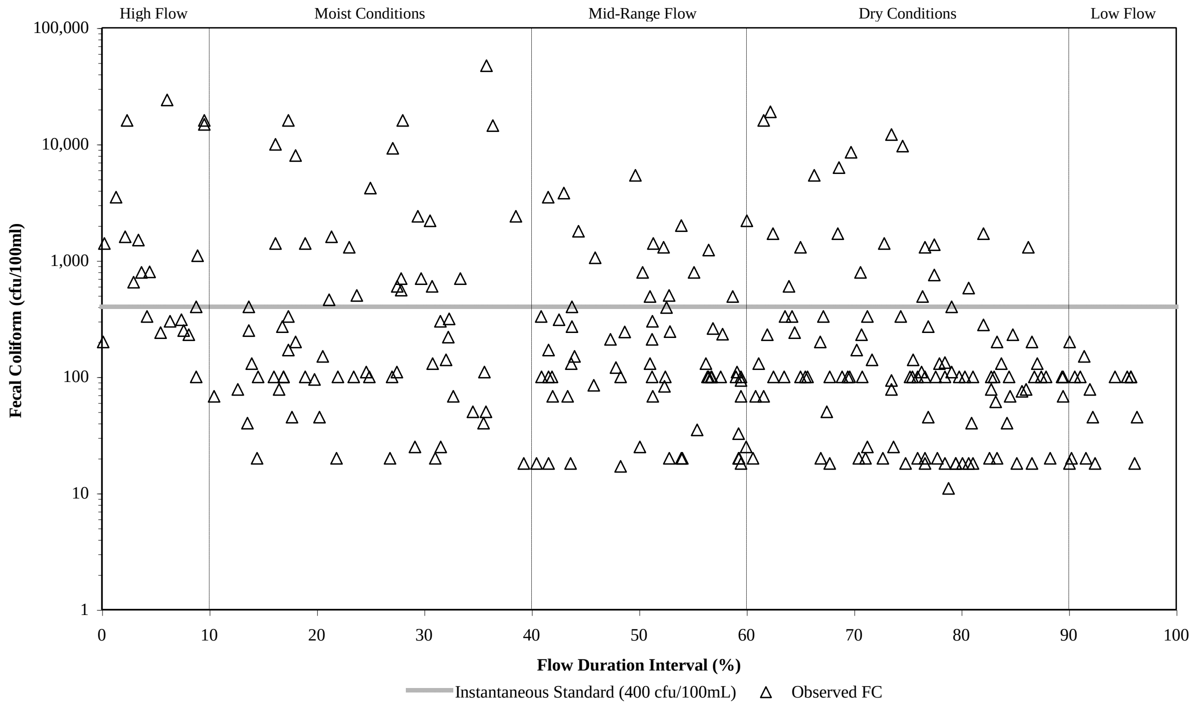

Figure B.20 Fecal coliform concentrations at 2-JMS099.30 in the James River versus discharge at USGS Gaging Station #02037500.

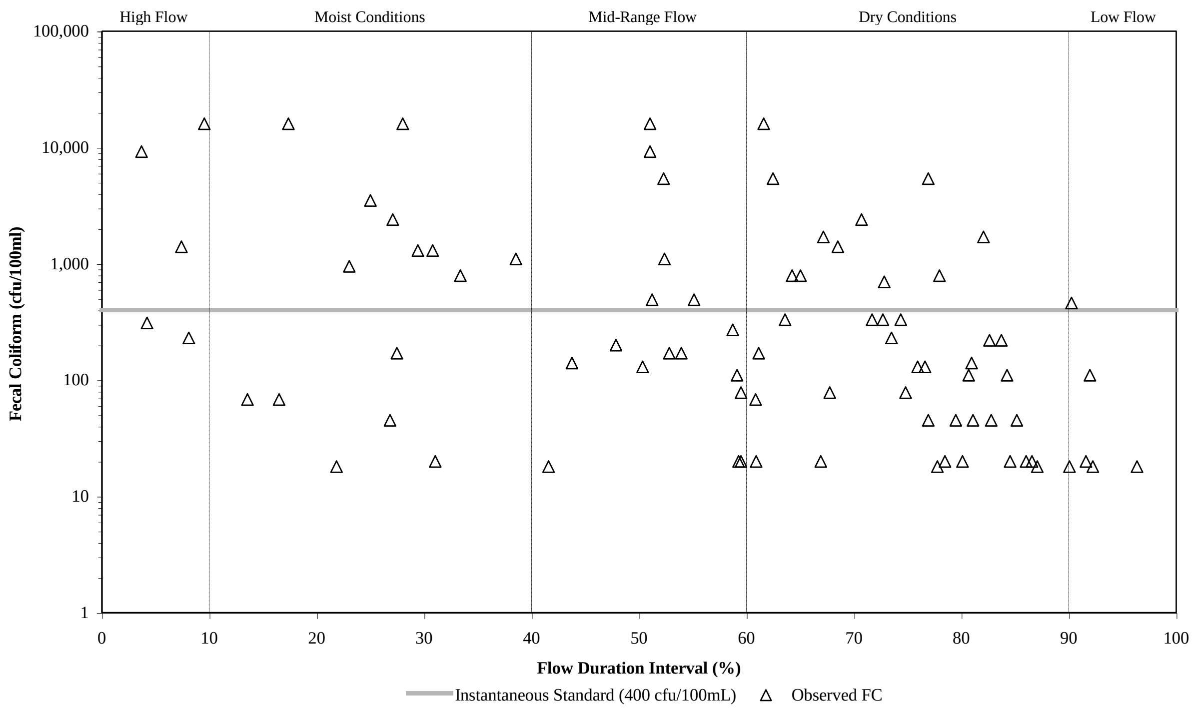

Figure B.21 Fecal coliform concentrations at 2-JMS101.03 in the James River versus discharge at USGS Gaging Station #02037500.

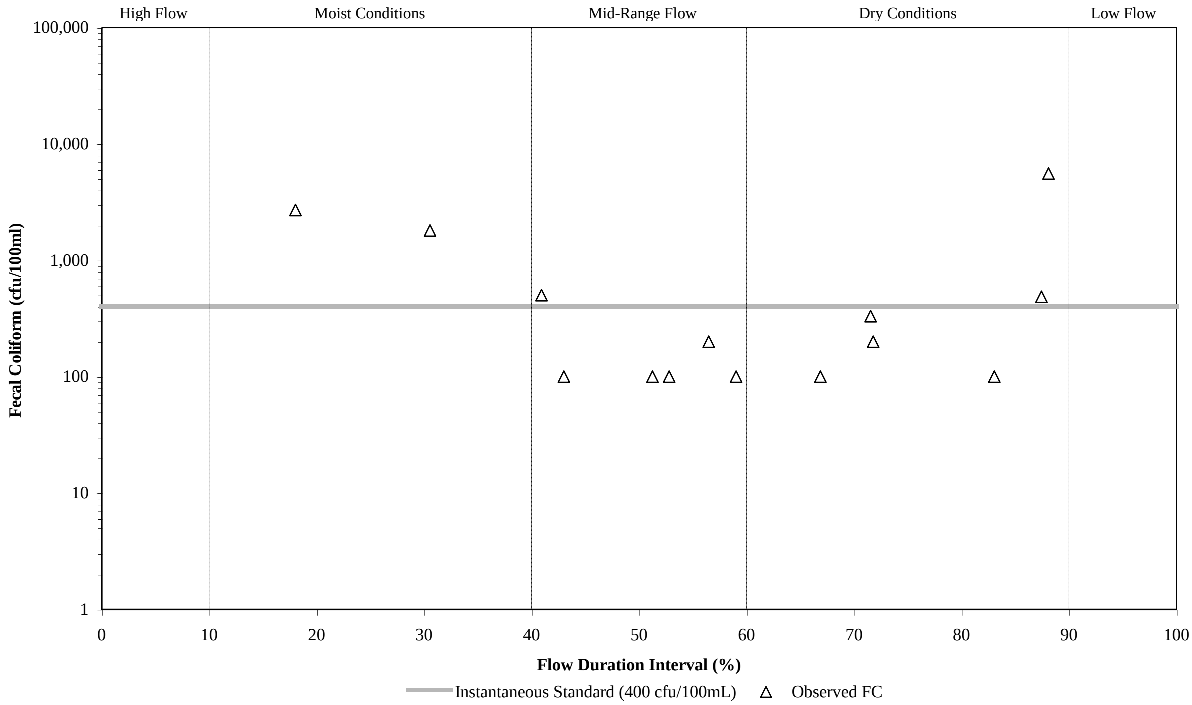

Figure B.22 Fecal coliform concentrations at 2-JMS102.76 in the James River versus discharge at USGS Gaging Station #02037500.

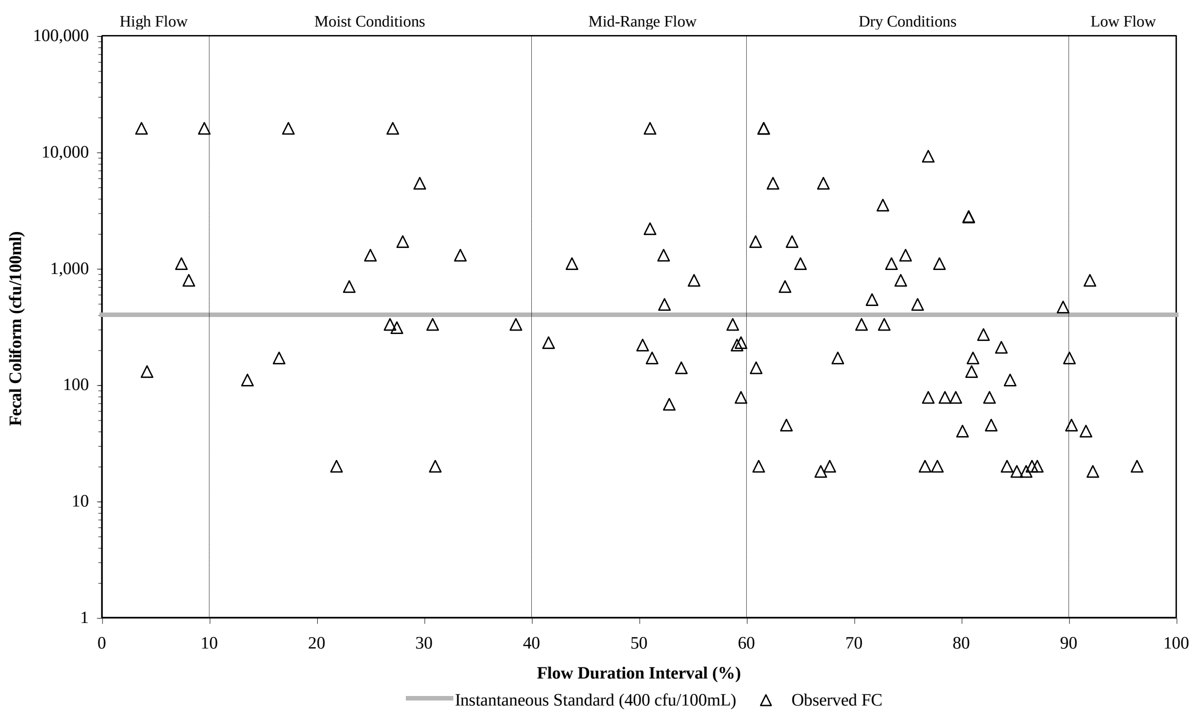

Figure B.23 Fecal coliform concentrations at 2-JMS103.15 in the James River versus discharge at USGS Gaging Station #02037500.

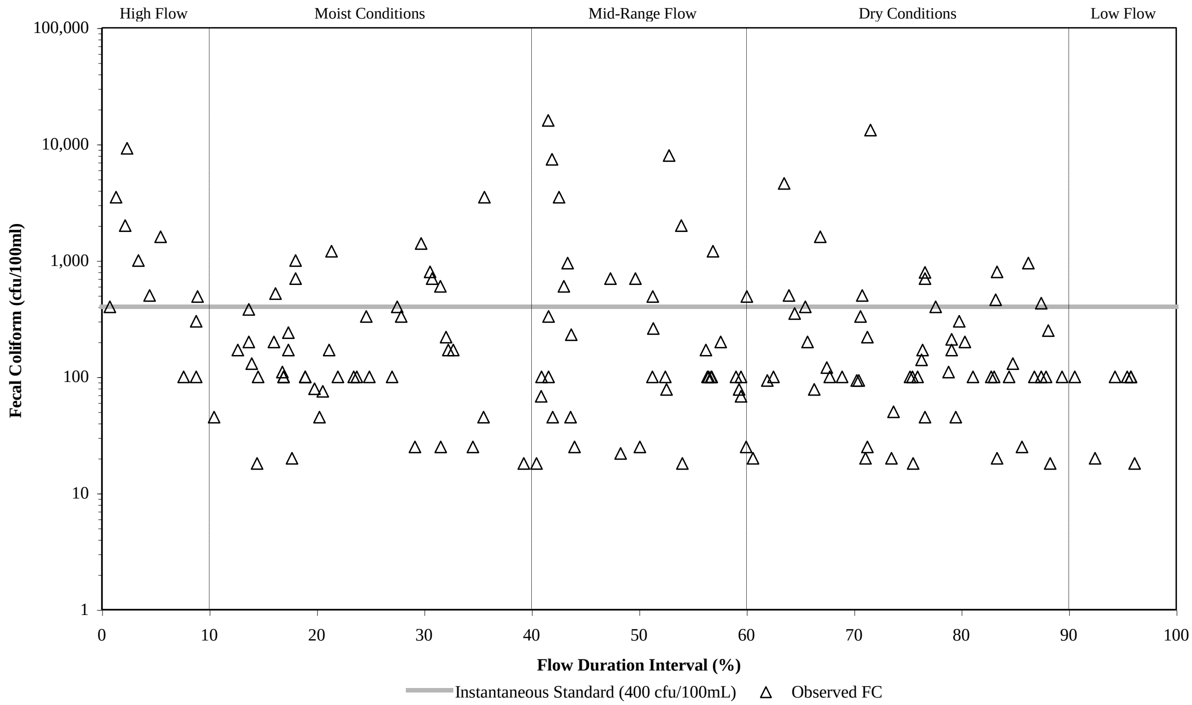

Figure B.24 Fecal coliform concentrations at 2-JMS104.16 in the James River versus discharge at USGS Gaging Station #02037500.

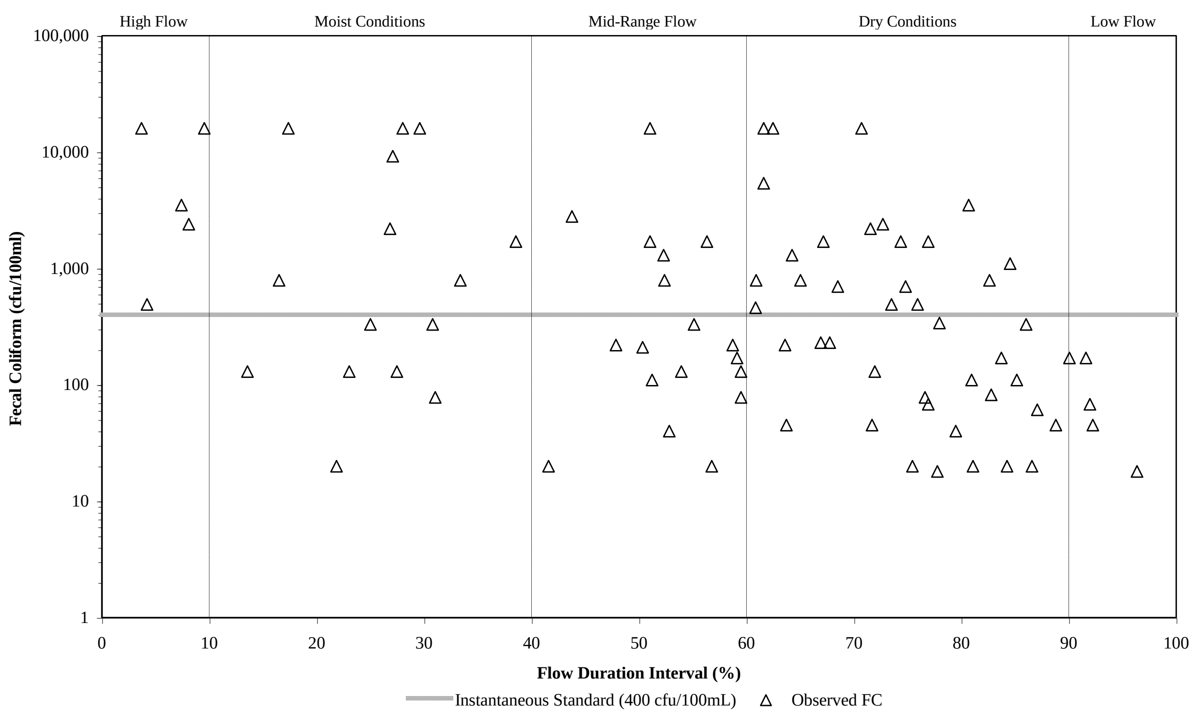

Figure B.25 Fecal coliform concentrations at 2-JMS104.58 in the James River versus discharge at USGS Gaging Station #02037500.

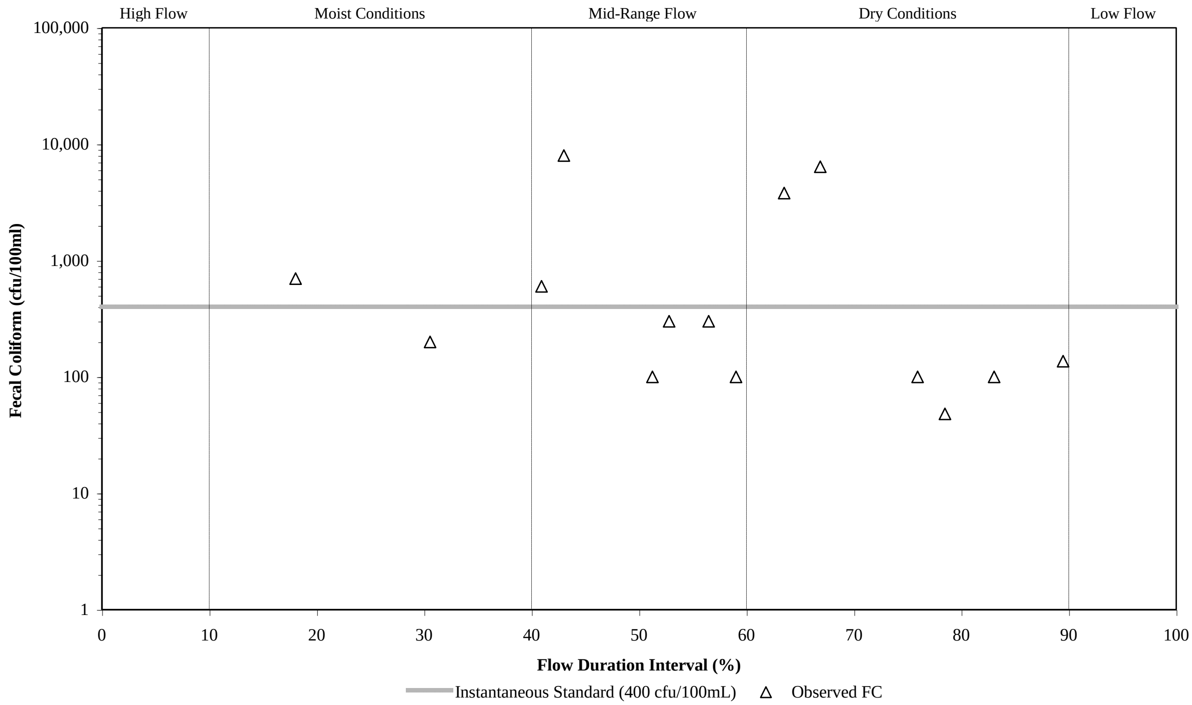

Figure B.26 Fecal coliform concentrations at 2-JMS107.04 in the James River versus discharge at USGS Gaging Station #02037500.

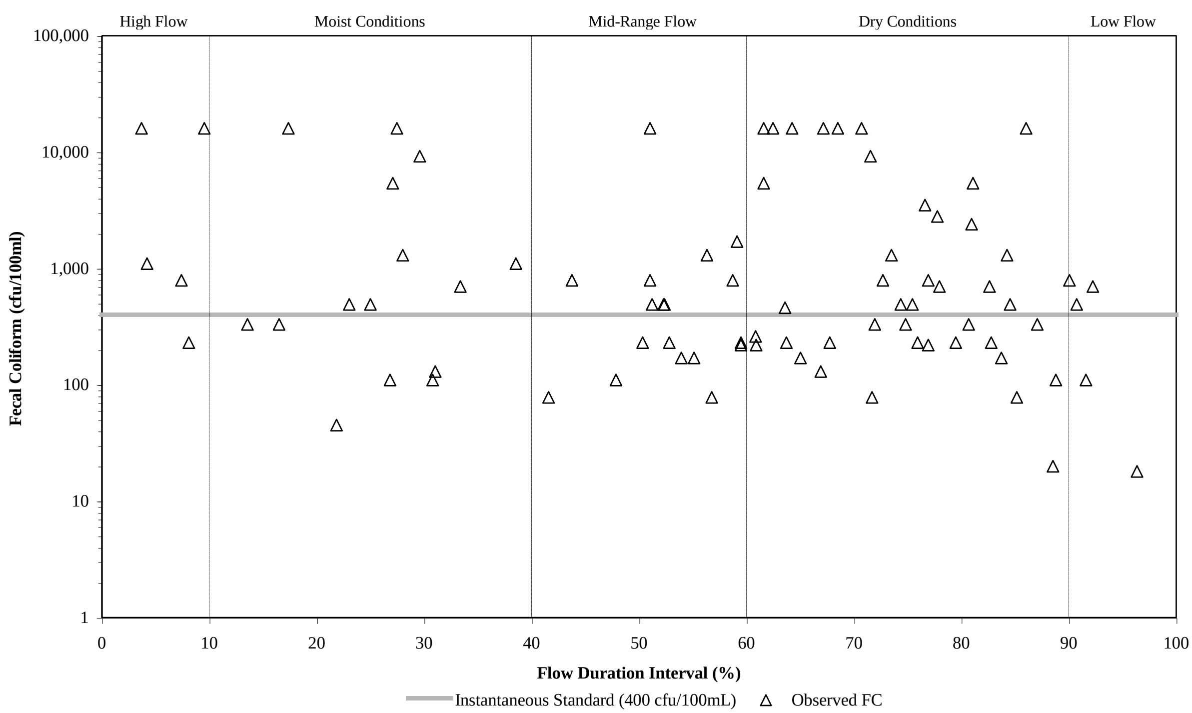

Figure B.27 Fecal coliform concentrations at 2-JMS107.51 in the James River versus discharge at USGS Gaging Station #02037500.

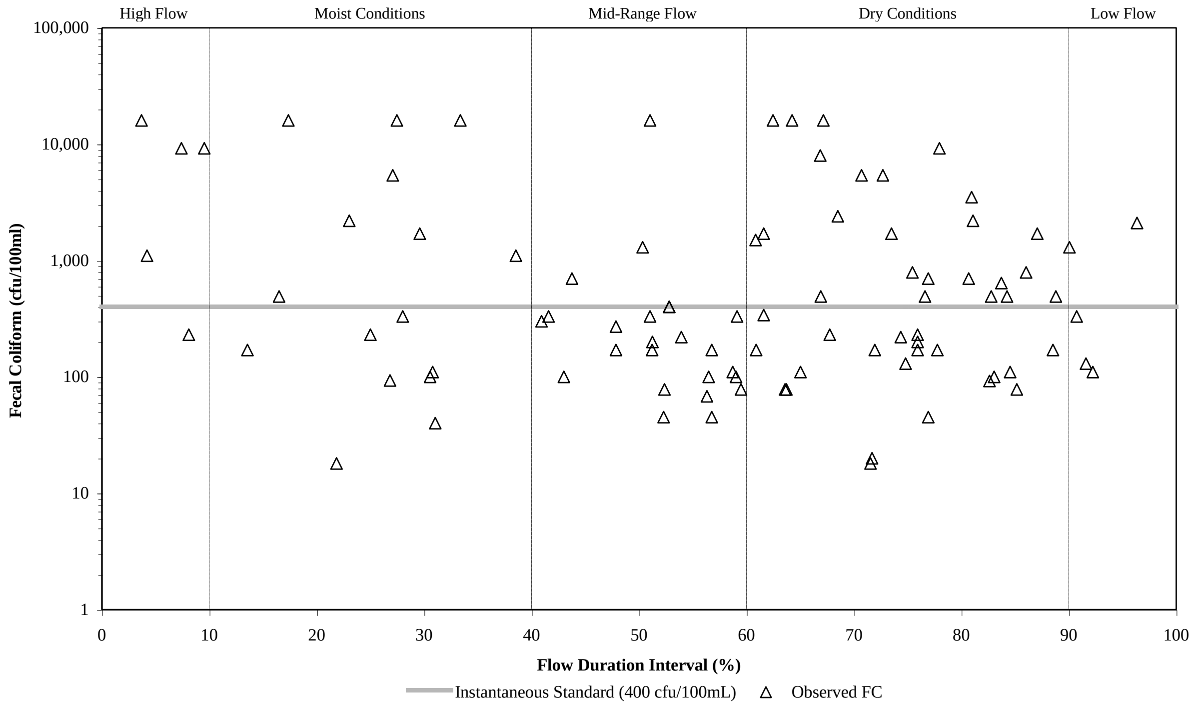

Figure B.28 Fecal coliform concentrations at 2-JMS109.39 in the James River versus discharge at USGS Gaging Station #02037500.

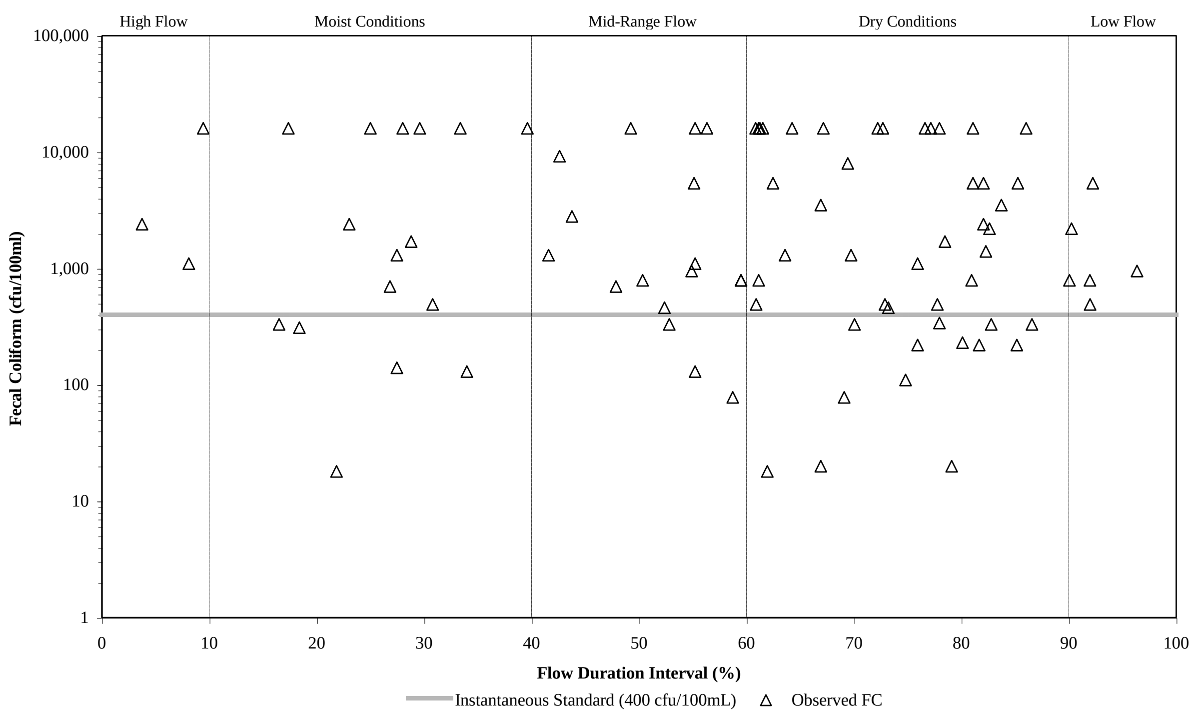

Figure B.29 Fecal coliform concentrations at 2-JMS110.07 in the James River versus discharge at USGS Gaging Station #02037500.

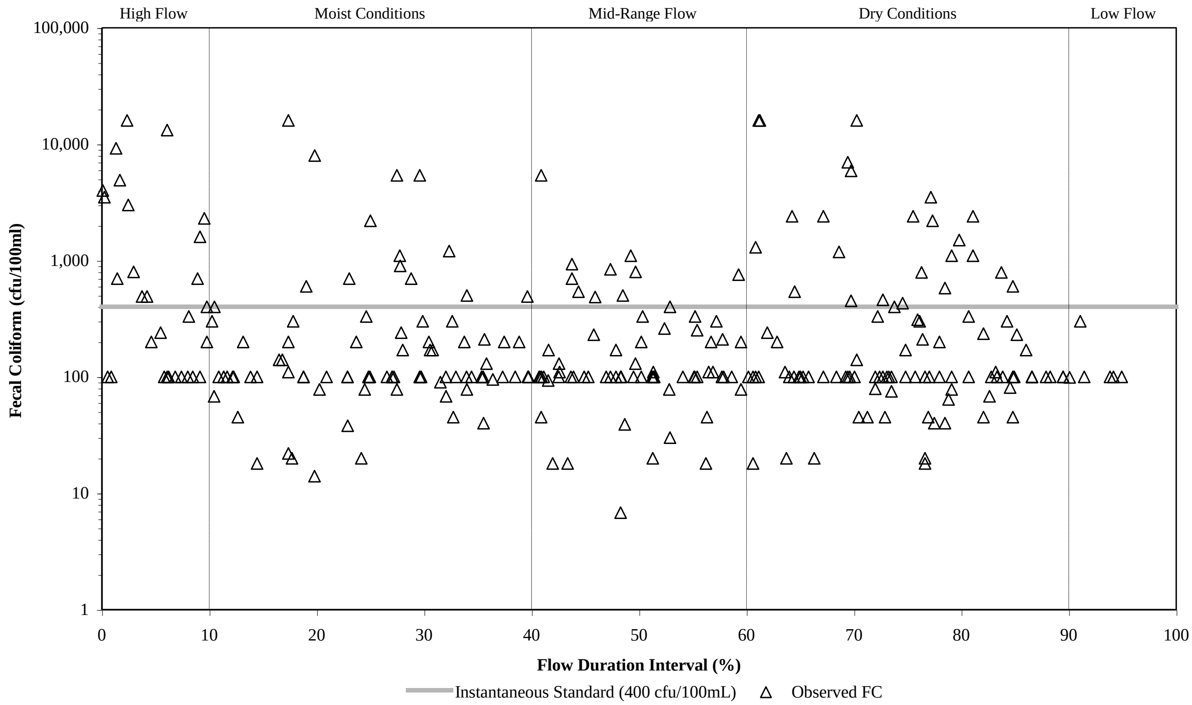

Figure B.30 Fecal coliform concentrations at 2-JMS110.30 in the James River versus discharge at USGS Gaging Station #02037500.

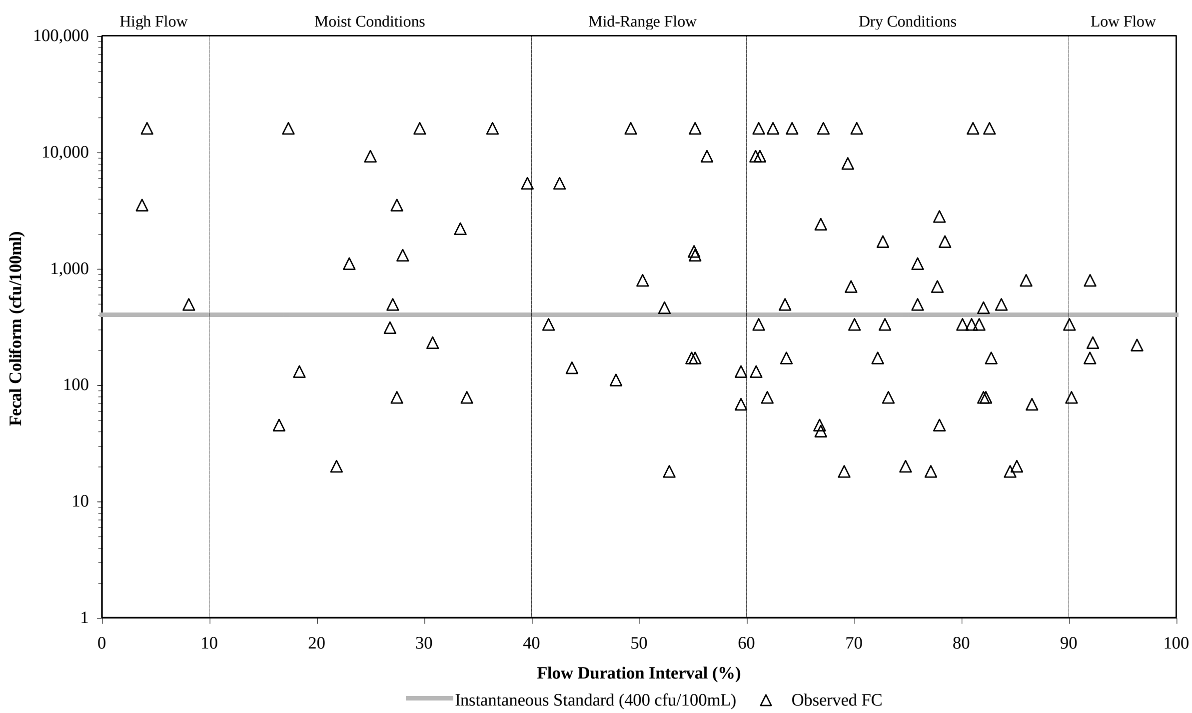

Figure B.31 Fecal coliform concentrations at 2-JMS110.31 in the James River versus discharge at USGS Gaging Station #02037500.

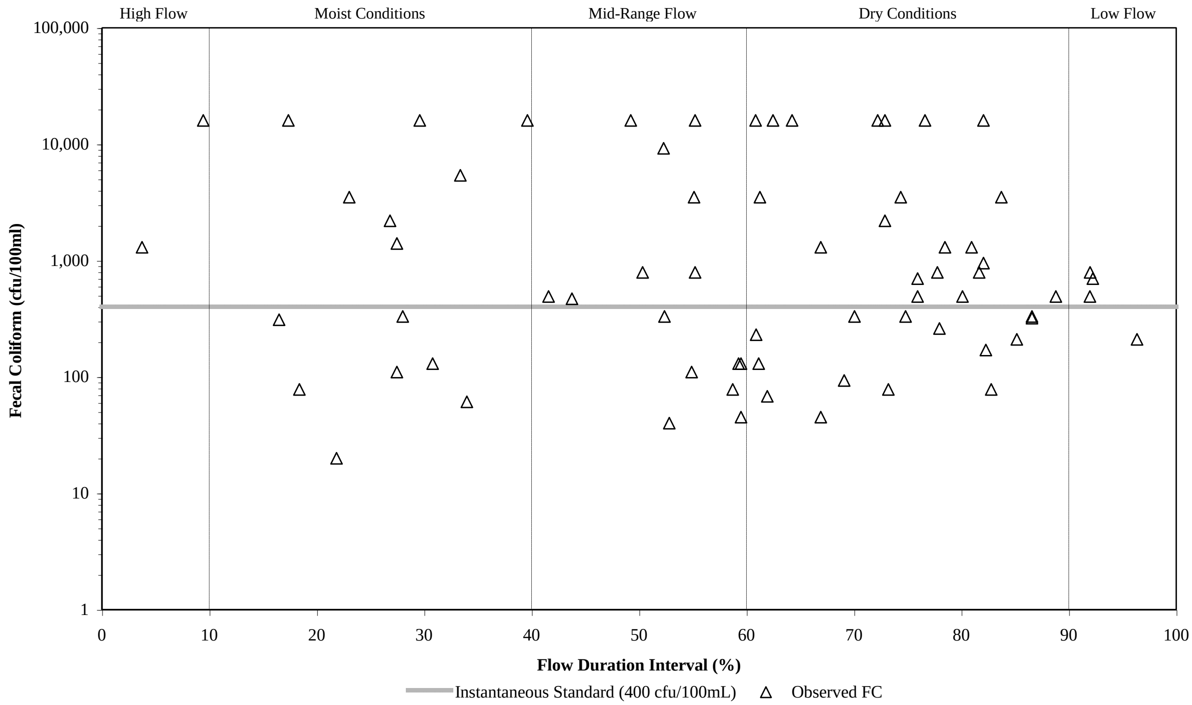

Figure B.32 Fecal coliform concentrations at 2-JMS110.49 in the James River versus discharge at USGS Gaging Station #02037500.

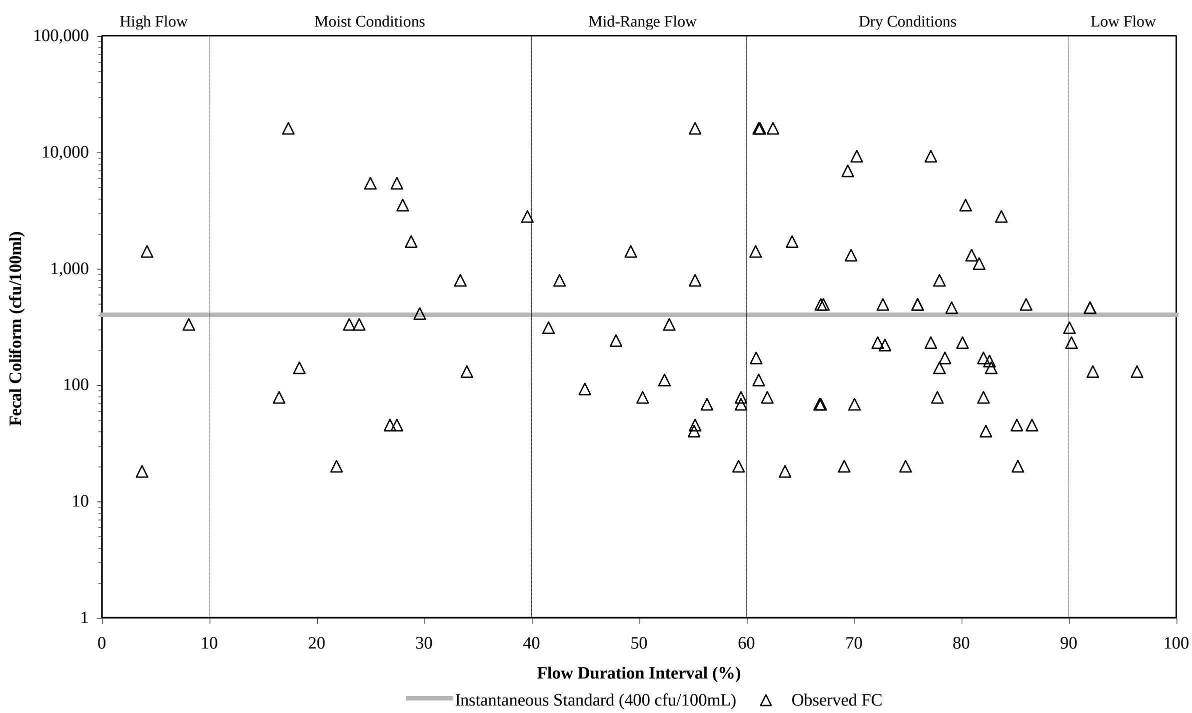

Figure B.33 Fecal coliform concentrations at 2-JMS110.90 in the James River versus discharge at USGS Gaging Station #02037500.

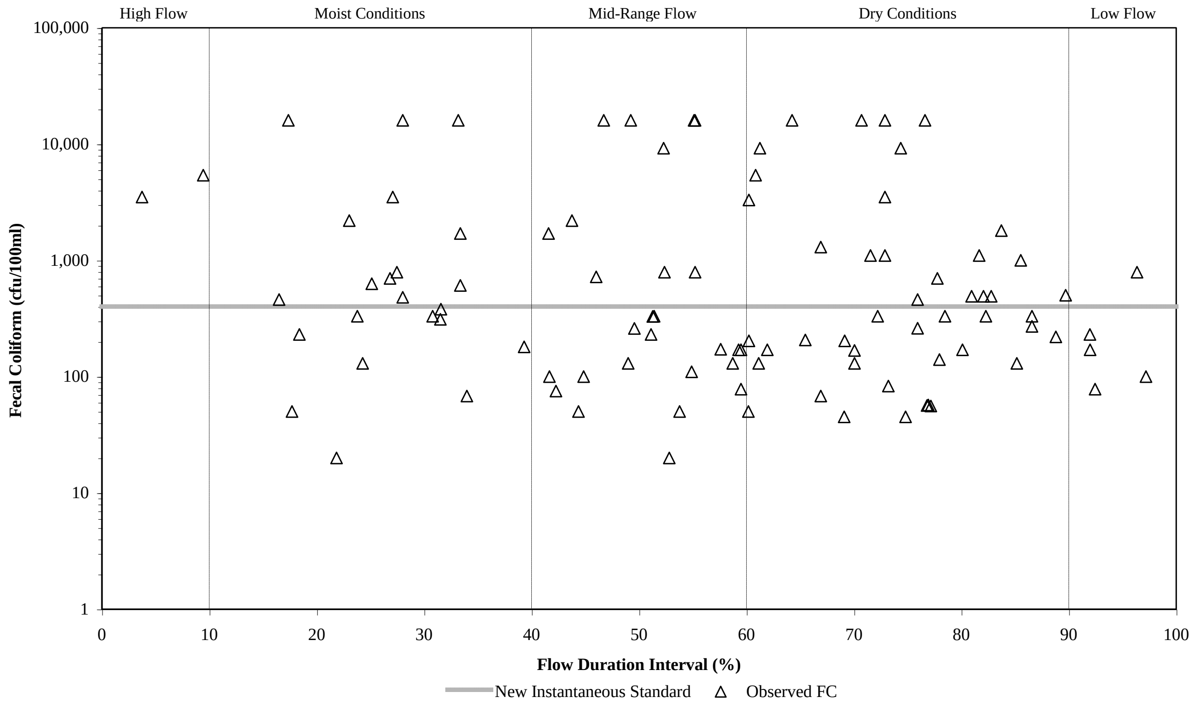

Figure B.34 Fecal coliform concentrations at 2-JMS111.17 in the James River versus discharge at USGS Gaging Station #02037500.

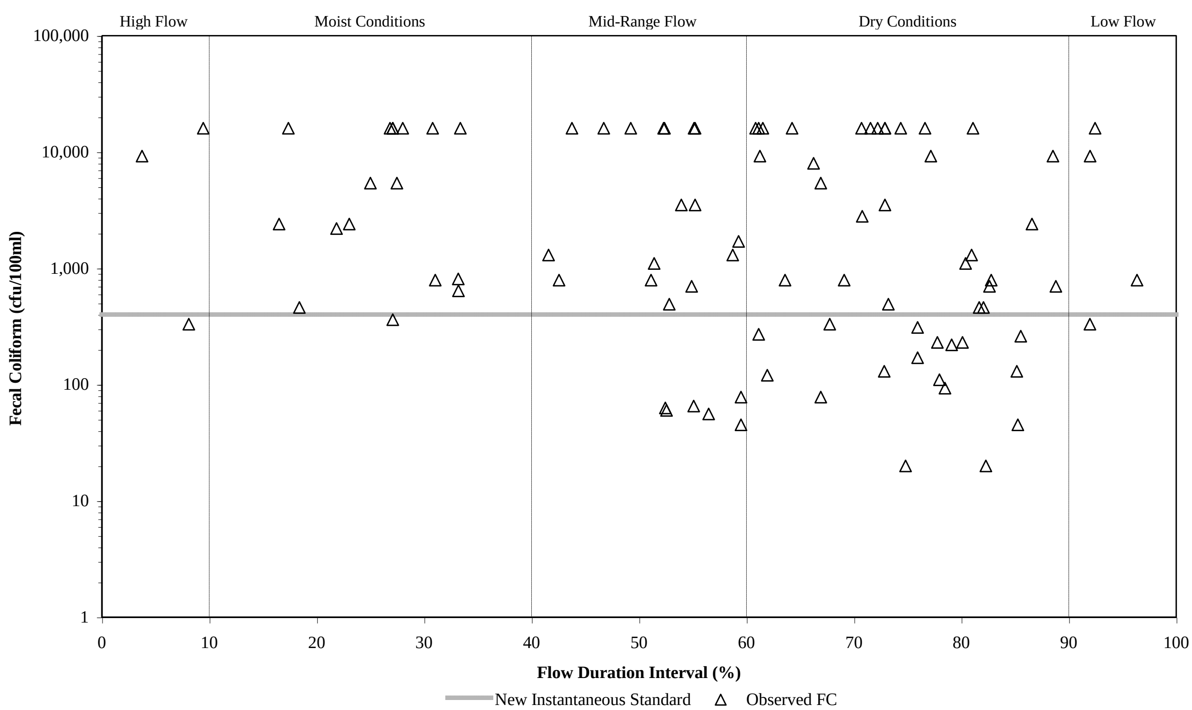

Figure B.35 Fecal coliform concentrations at 2-JMS111.32 in the James River versus discharge at USGS Gaging Station #02037500.

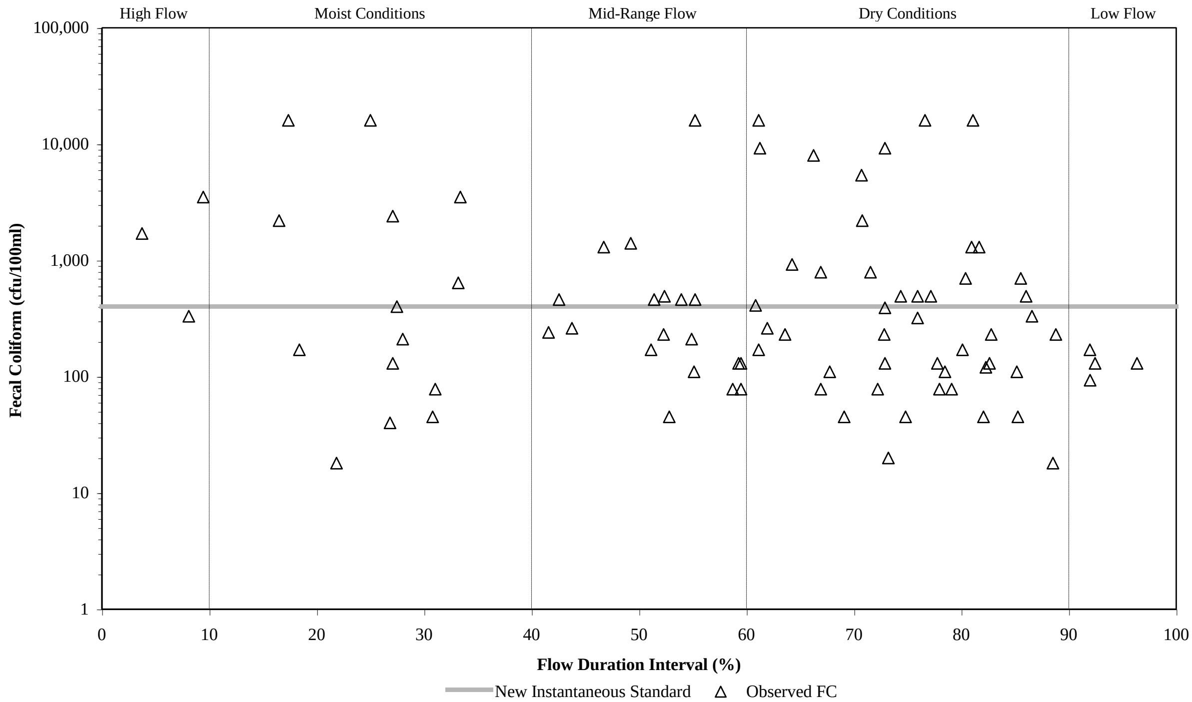

Figure B.36 Fecal coliform concentrations at 2-JMS111.35 in the James River versus discharge at USGS Gaging Station #02037500.

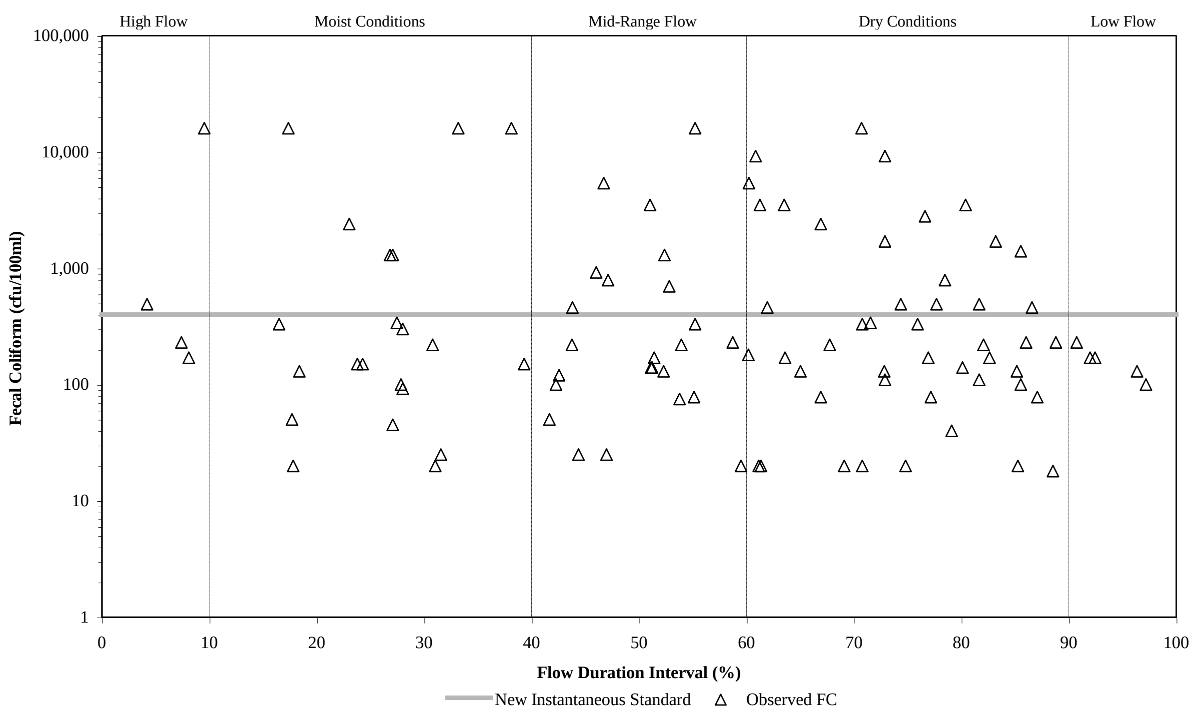

Figure B.37 Fecal coliform concentrations at 2-JMS111.47 in the James River versus discharge at USGS Gaging Station #02037500.

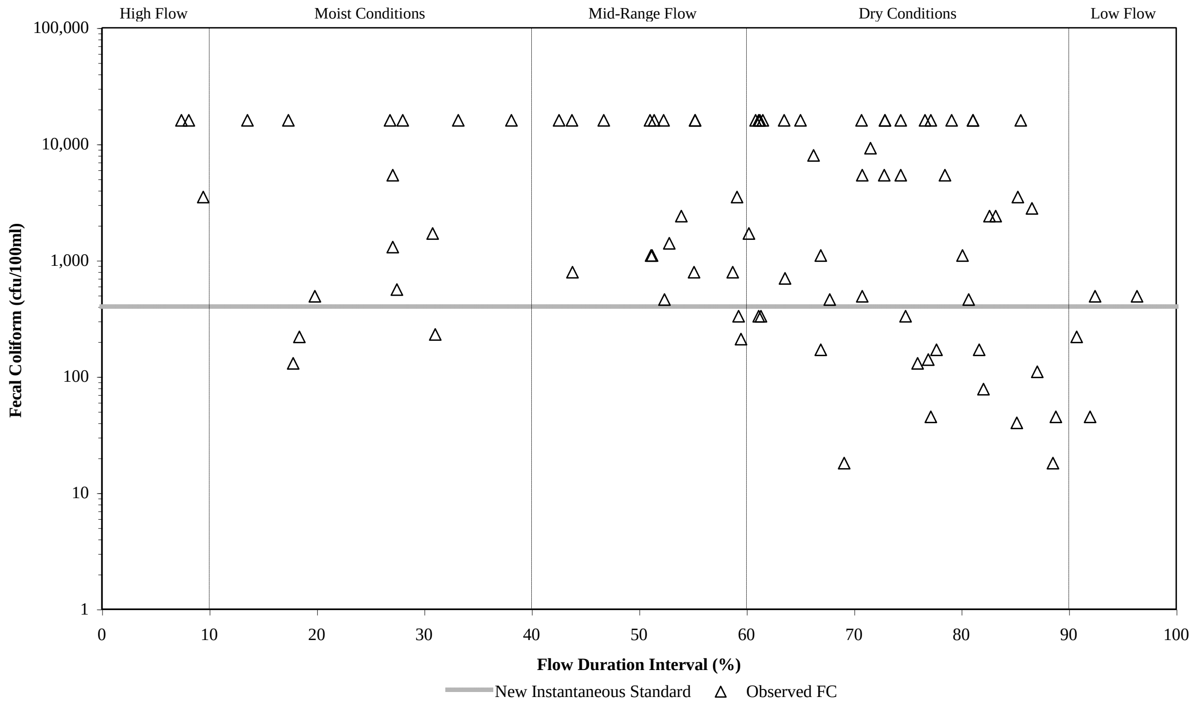

Figure B.38 Fecal coliform concentrations at 2-JMS111.48 in the James River versus discharge at USGS Gaging Station #02037500.

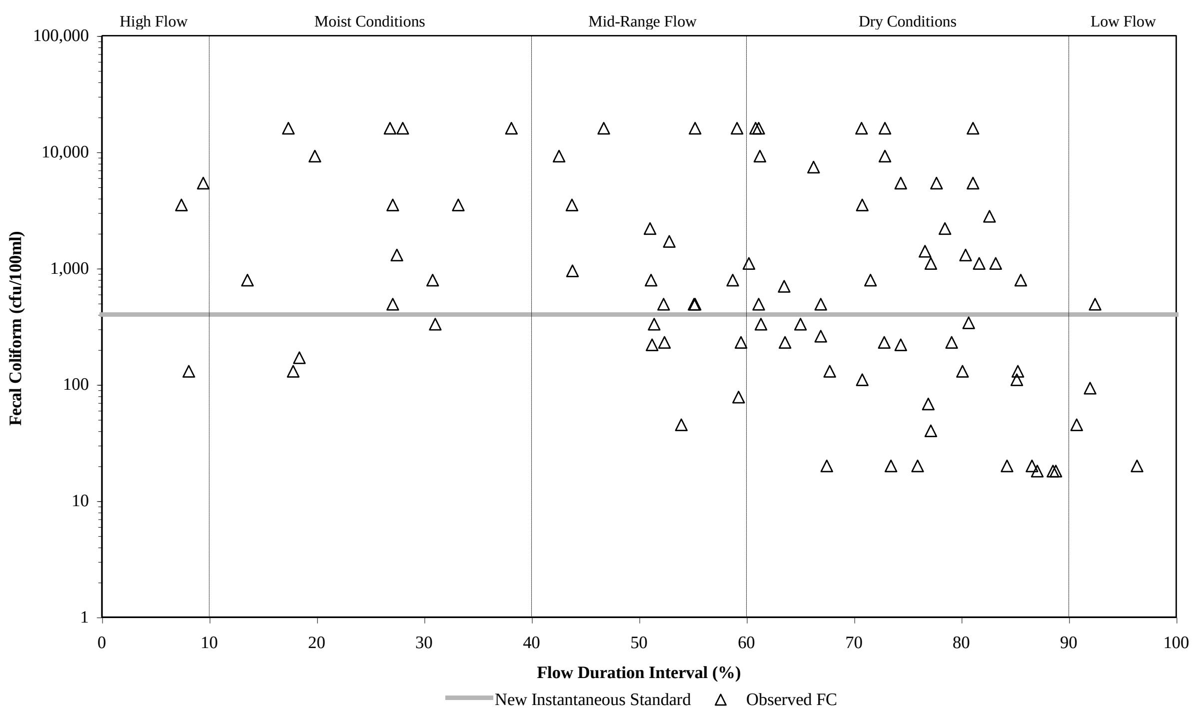

Figure B.39 Fecal coliform concentrations at 2-JMS111.55 in the James River versus discharge at USGS Gaging Station #02037500.

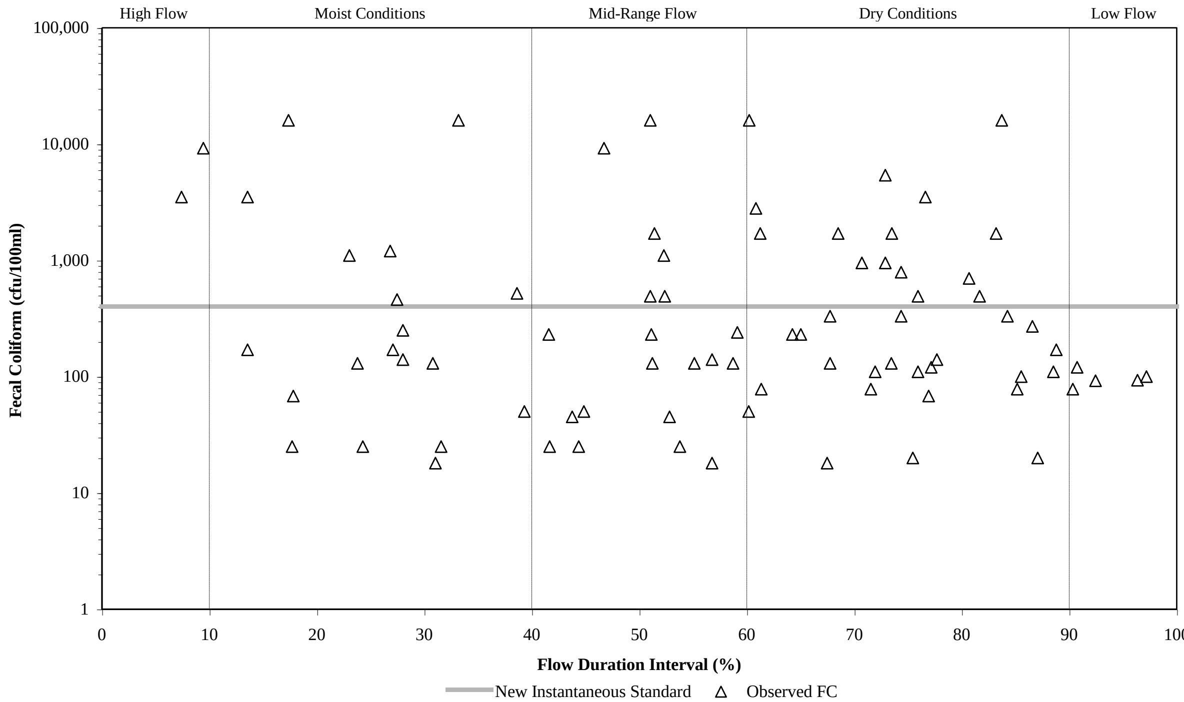

Figure B.40 Fecal coliform concentrations at 2-JMS112.33 in the James River versus discharge at USGS Gaging Station #02037500.

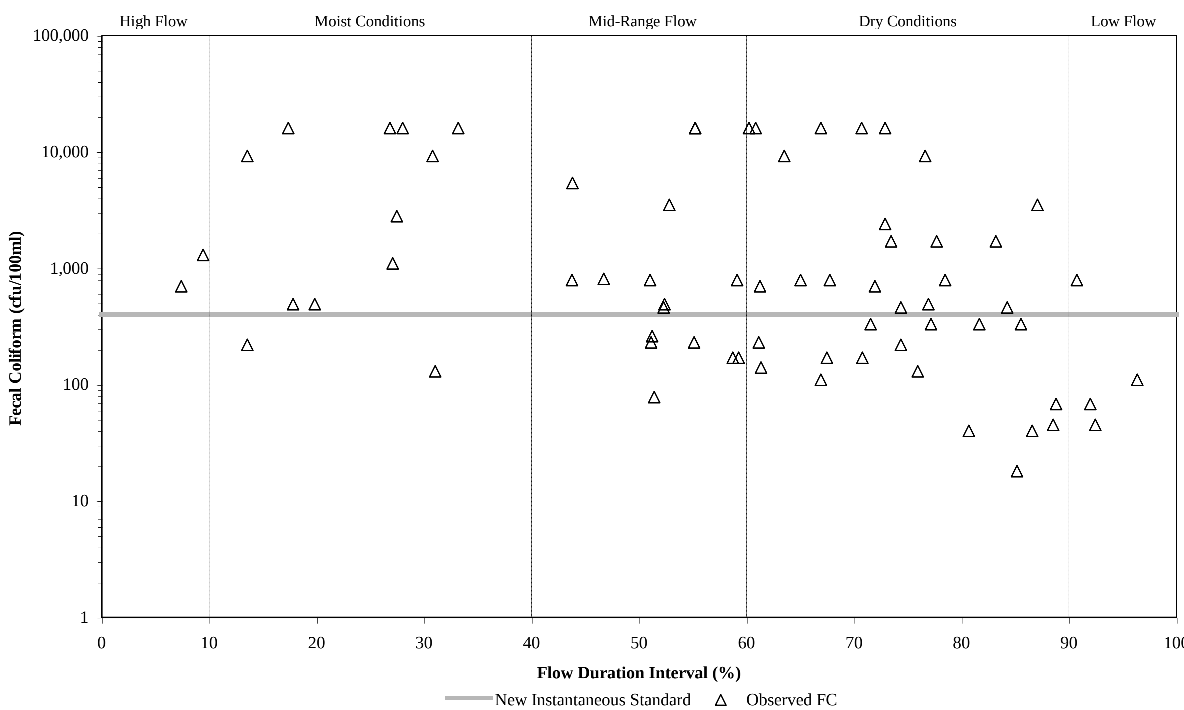

Figure B.41 Fecal coliform concentrations at 2-JMS112.37 in the James River versus discharge at USGS Gaging Station #02037500.

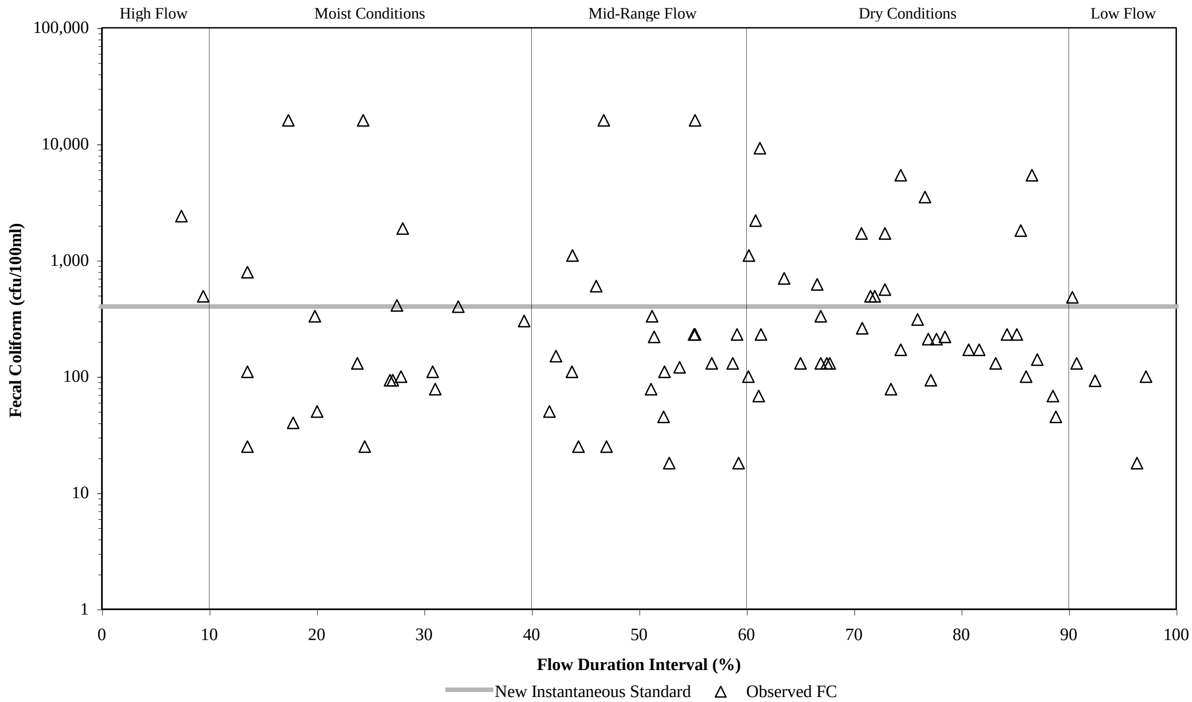

Figure B.42 Fecal coliform concentrations at 2-JMS112.79 in the James River versus discharge at USGS Gaging Station #02037500.

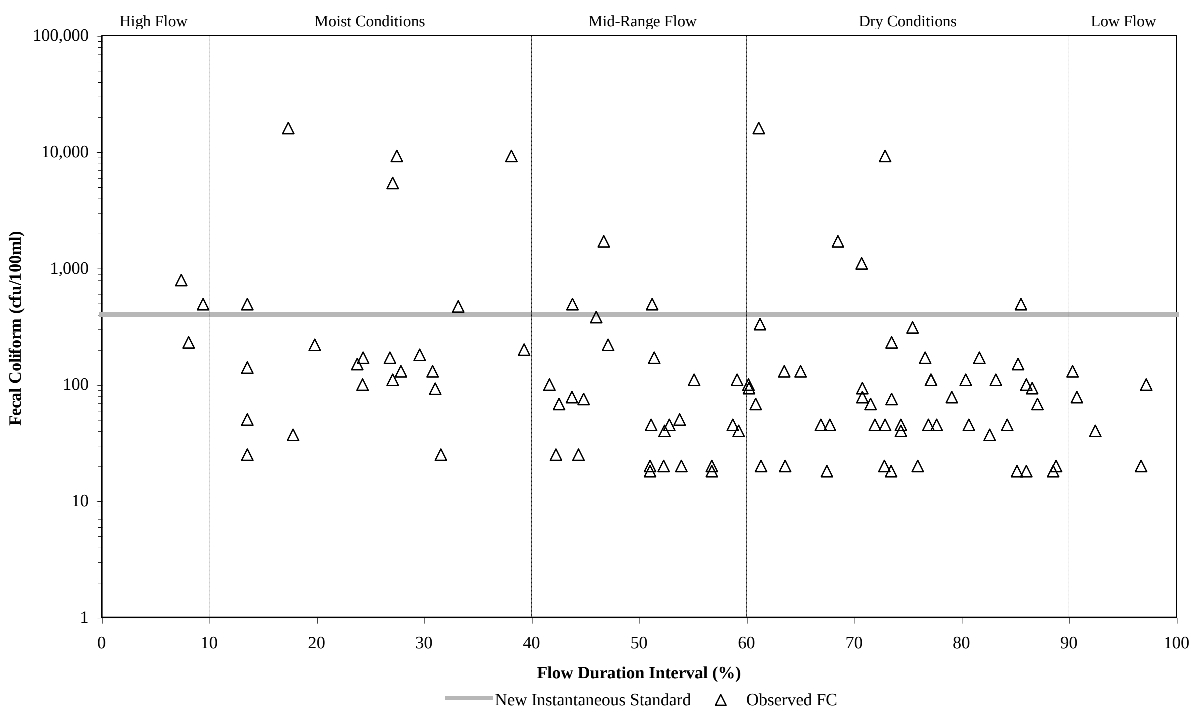

Figure B.43 Fecal coliform concentrations at 2-JMS115.29 in the James River versus discharge at USGS Gaging Station #02037500.

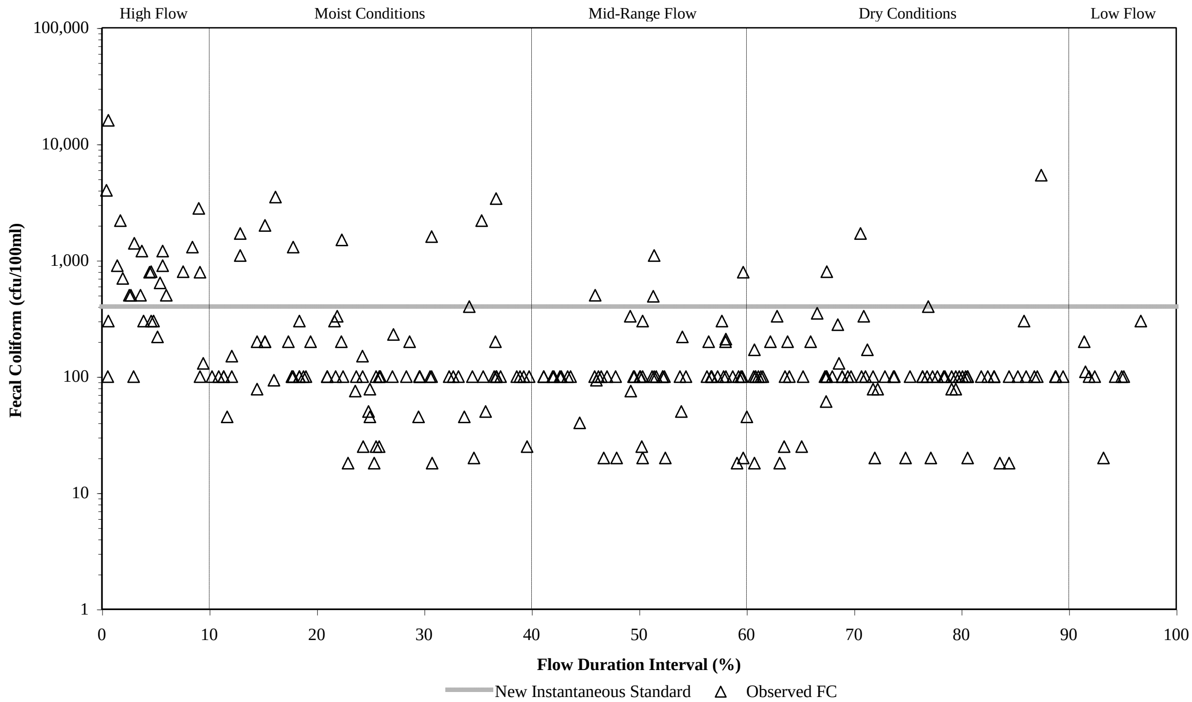

Figure B.44 Fecal coliform concentrations at 2-JMS117.35 in the James River versus discharge at USGS Gaging Station #02037500.

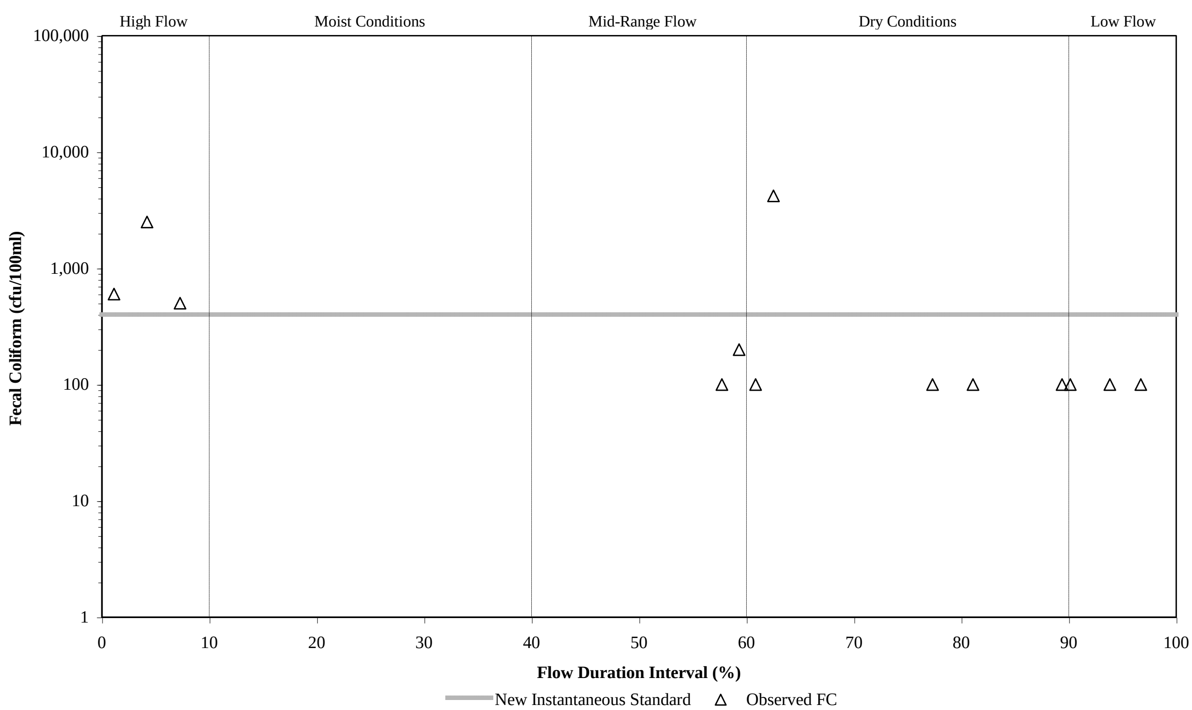

Figure B.45 Fecal coliform concentrations at 2-JMS127.50 in the James River versus discharge at USGS Gaging Station #02037500.

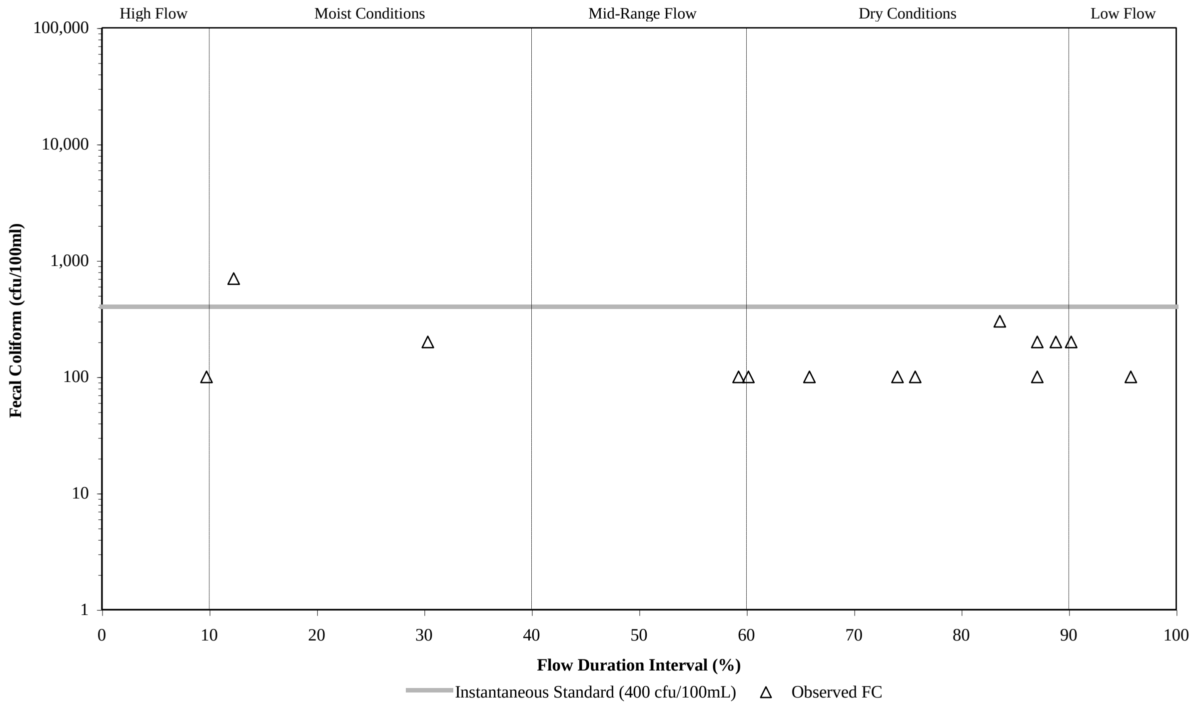

Figure B.46 Fecal coliform concentrations at 2-JOD001.19 in the Johnson Creek versus discharge at USGS Gaging Station #02037500.

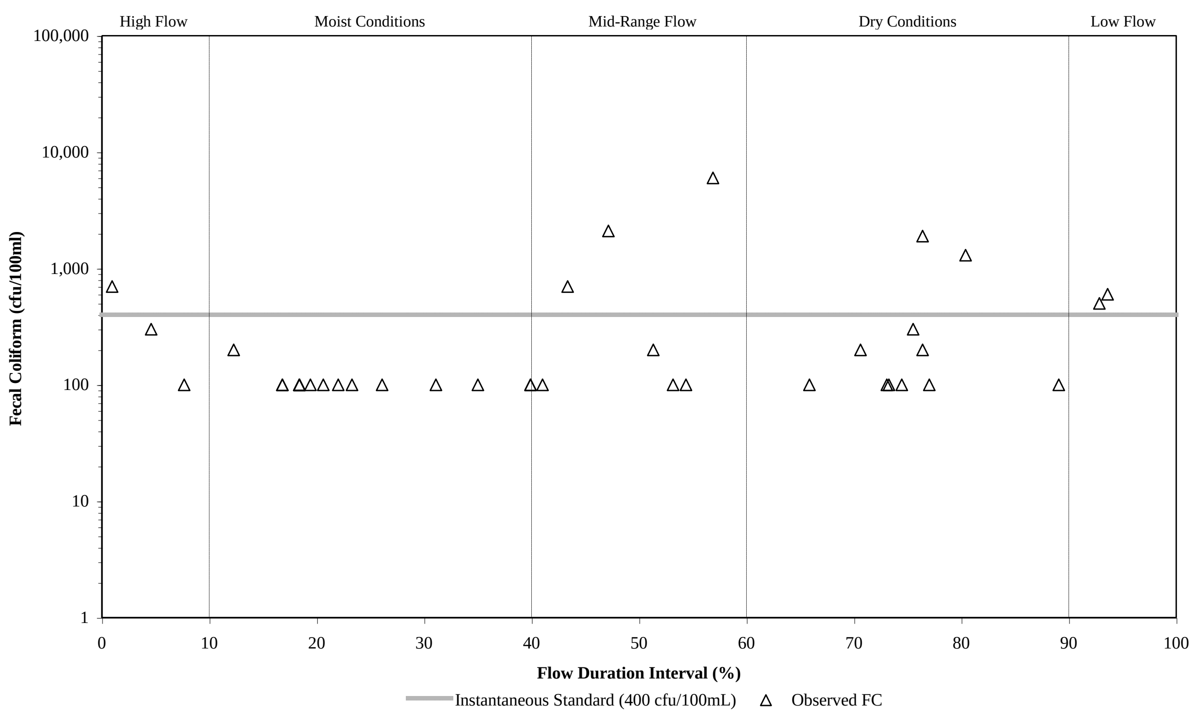

Figure B.47 Fecal coliform concentrations at 2-JOD001.96 in the Johnson Creek versus discharge at USGS Gaging Station #02037500.

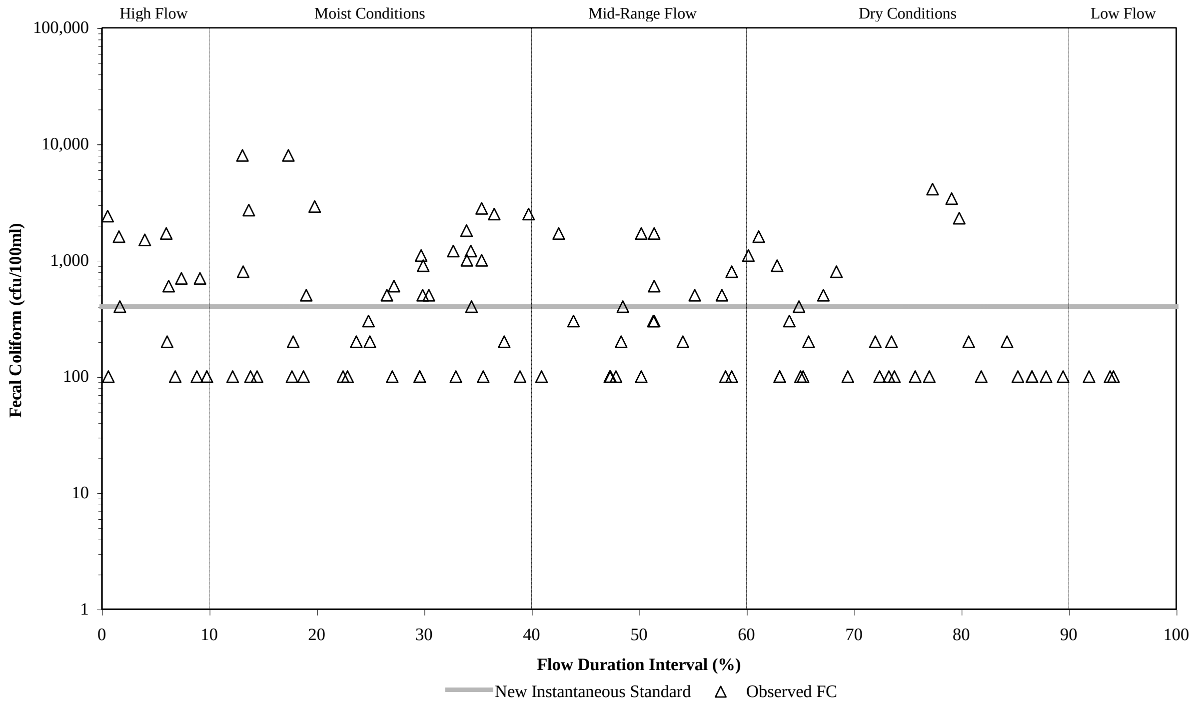

Figure B.48 Fecal coliform concentrations at 2-KSL000.18 in Kingsland Creek versus discharge at USGS Gaging Station #02037500.

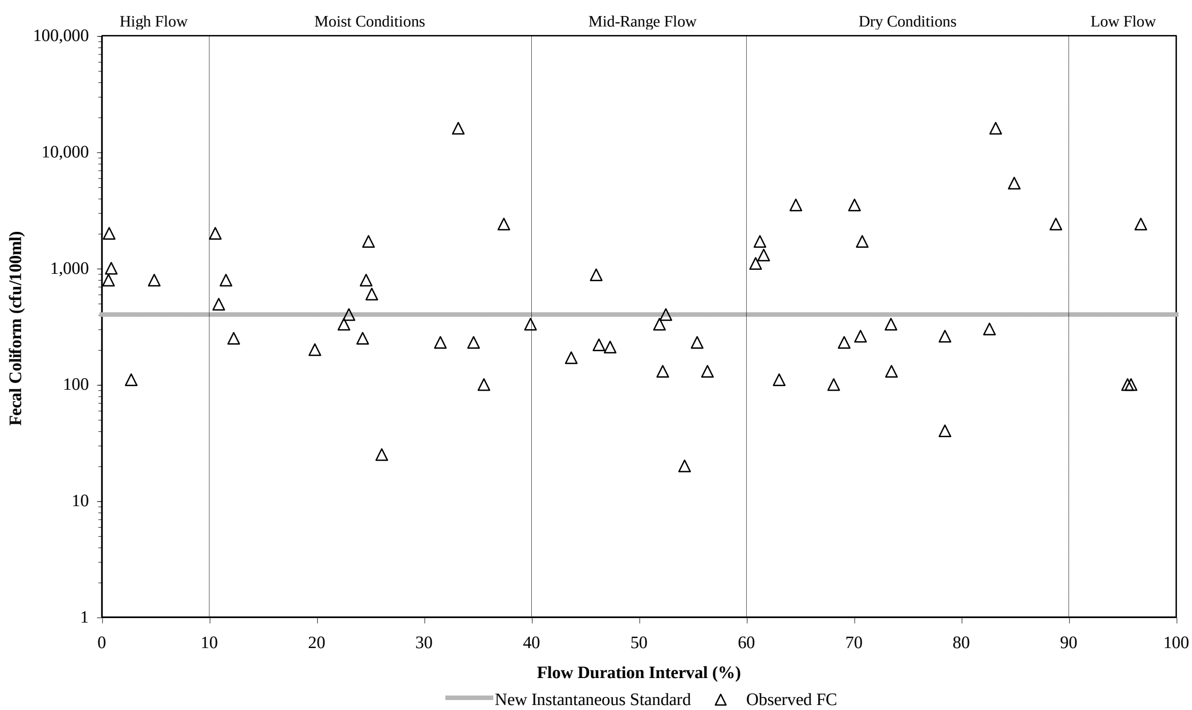

Figure B.49 Fecal coliform concentrations at 2-LIY001.73 in Little Tuckahoe Creek versus discharge at USGS Gaging Station #02037500.

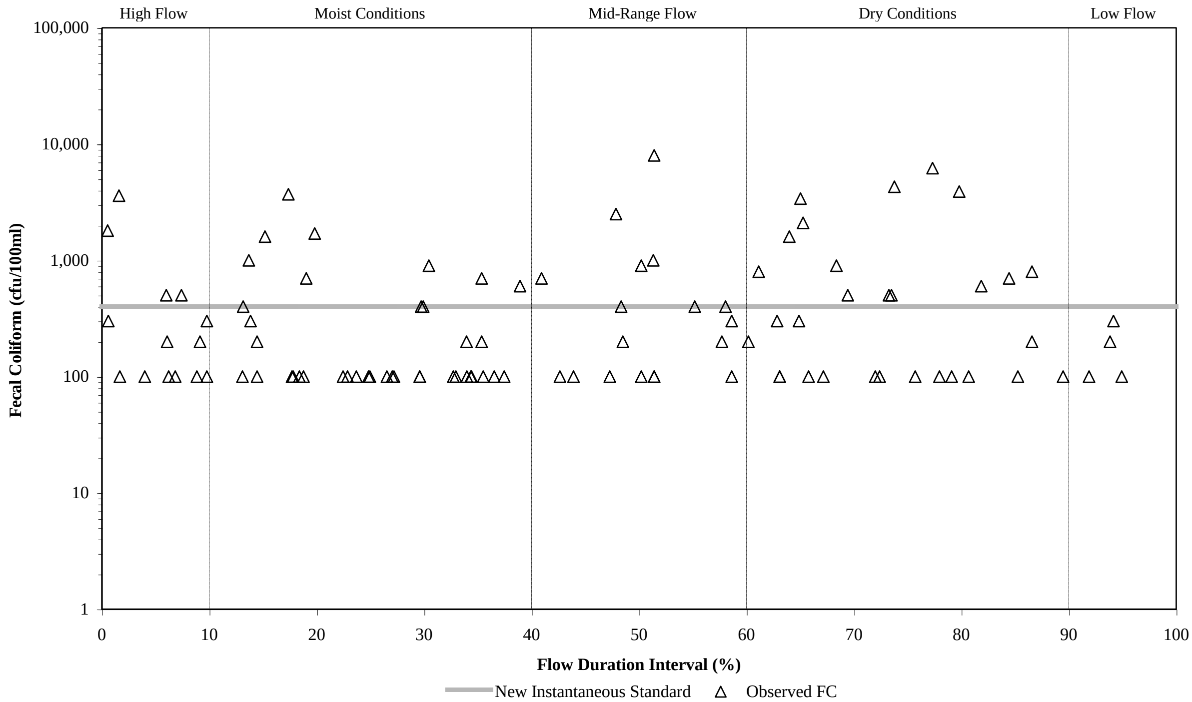

Figure B.50 Fecal coliform concentrations at 2-PCT002.46 in Proctors Creek versus discharge at USGS Gaging Station #02037500.

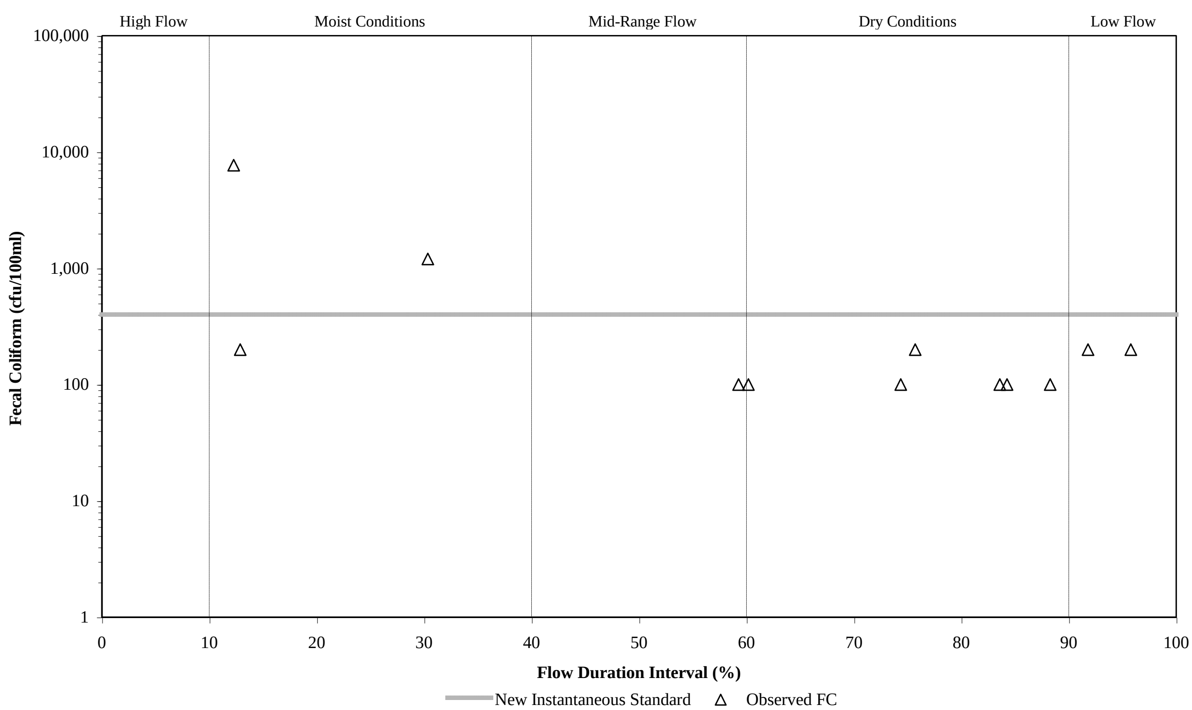

Figure B.51 Fecal coliform concentrations at 2-PSK000.23 in Pocoshock Creek versus discharge at USGS Gaging Station #02037500.

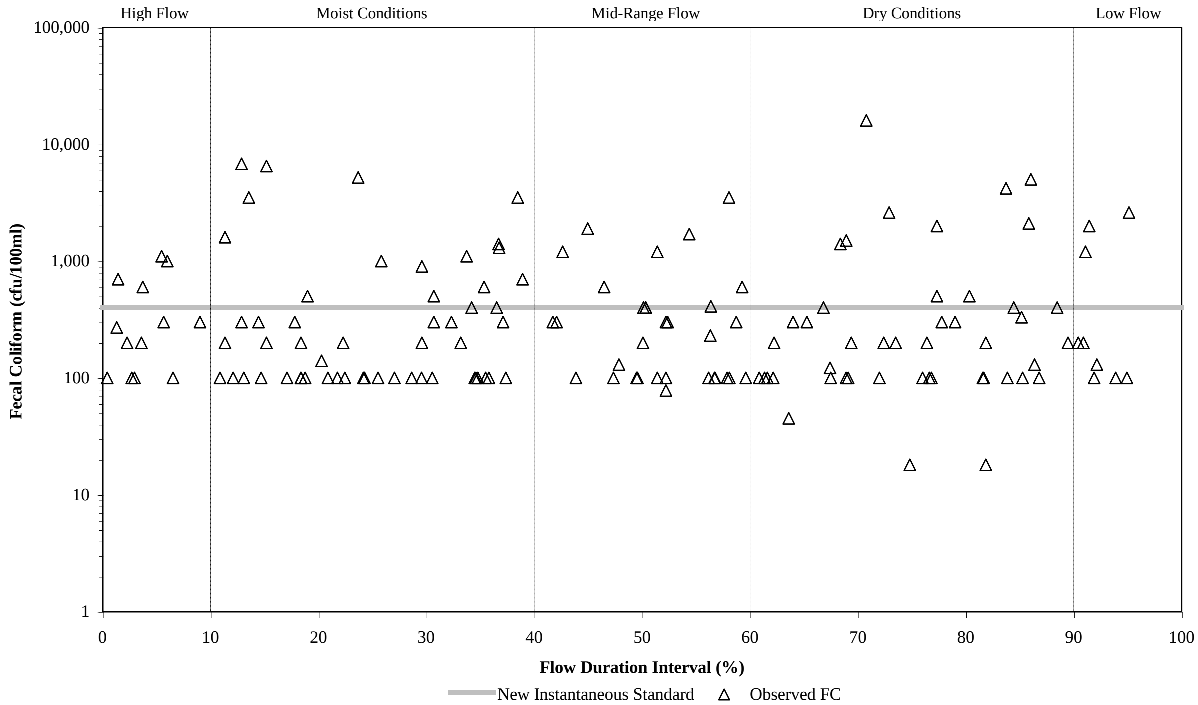

Figure B.52 Fecal coliform concentrations at 2-PWT000.57 in Powhite Creek versus discharge at USGS Gaging Station #02037500.

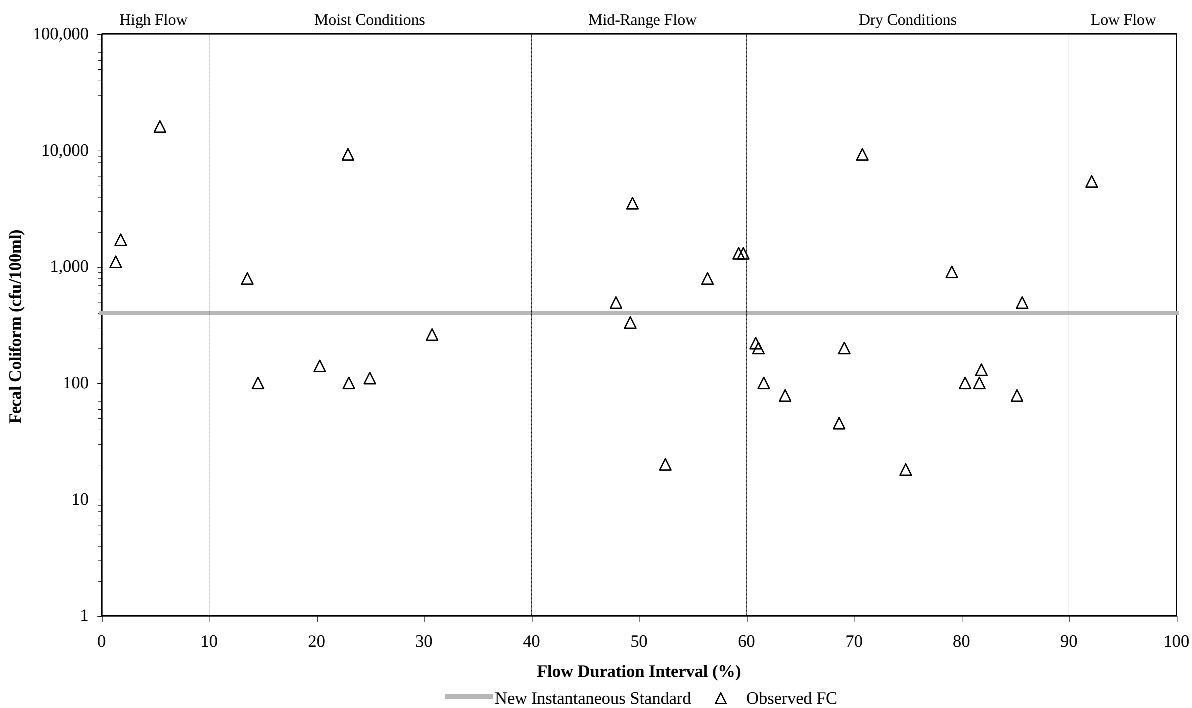

Figure B.53 Fecal coliform concentrations at 2-RDD000.19 in Reedy Creek versus discharge at USGS Gaging Station #02037500.

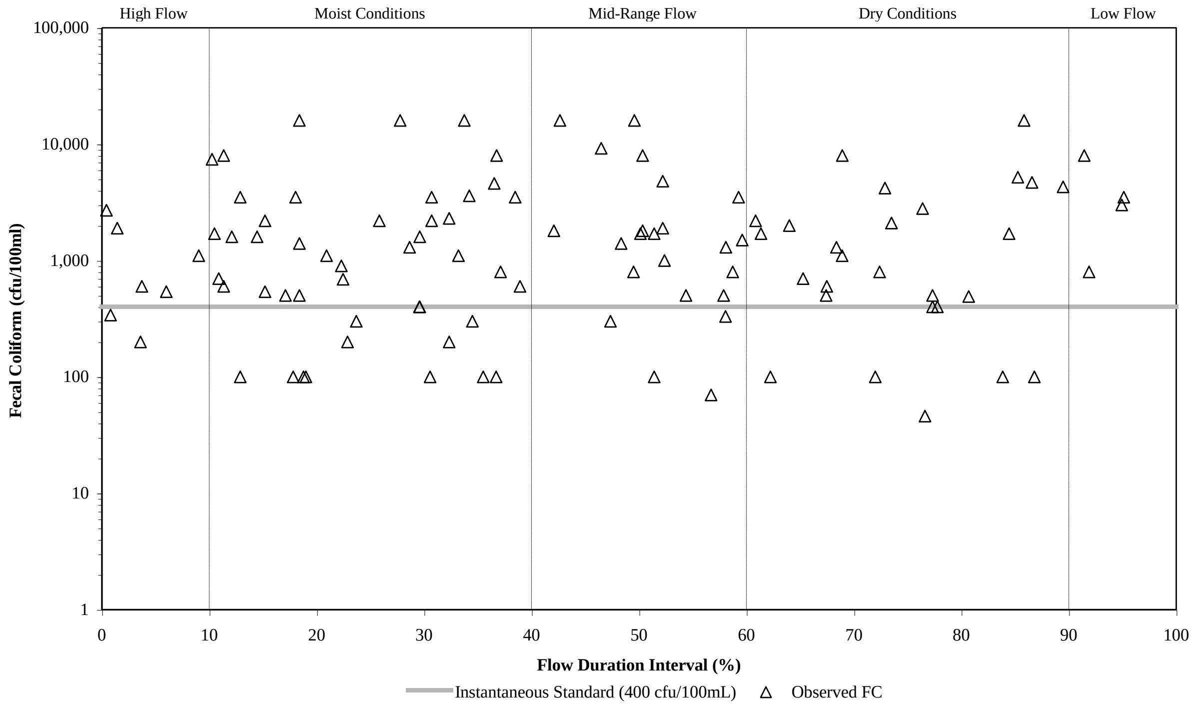

Figure B.54 Fecal coliform concentrations at 2-RDD000.76 in Reedy Creek versus discharge at USGS Gaging Station #02037500.

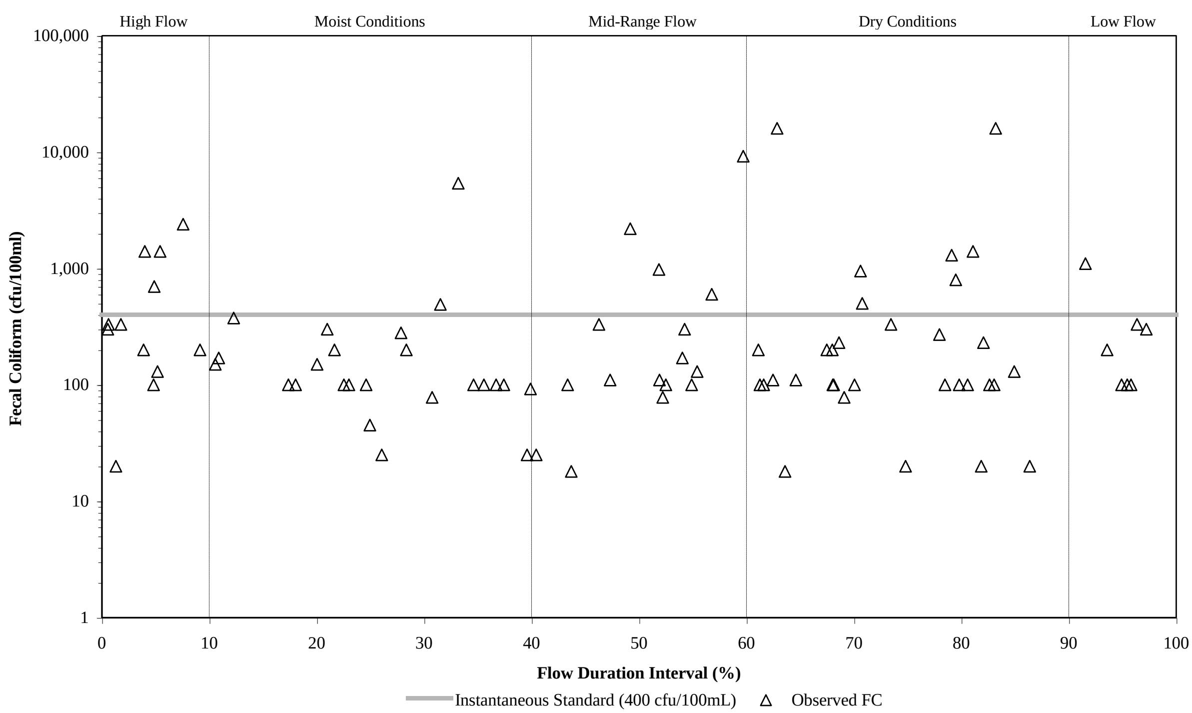

Figure B.55 Fecal coliform concentrations at 2-TKO004.69 in Tuckahoe Creek versus discharge at USGS Gaging Station #02037500.

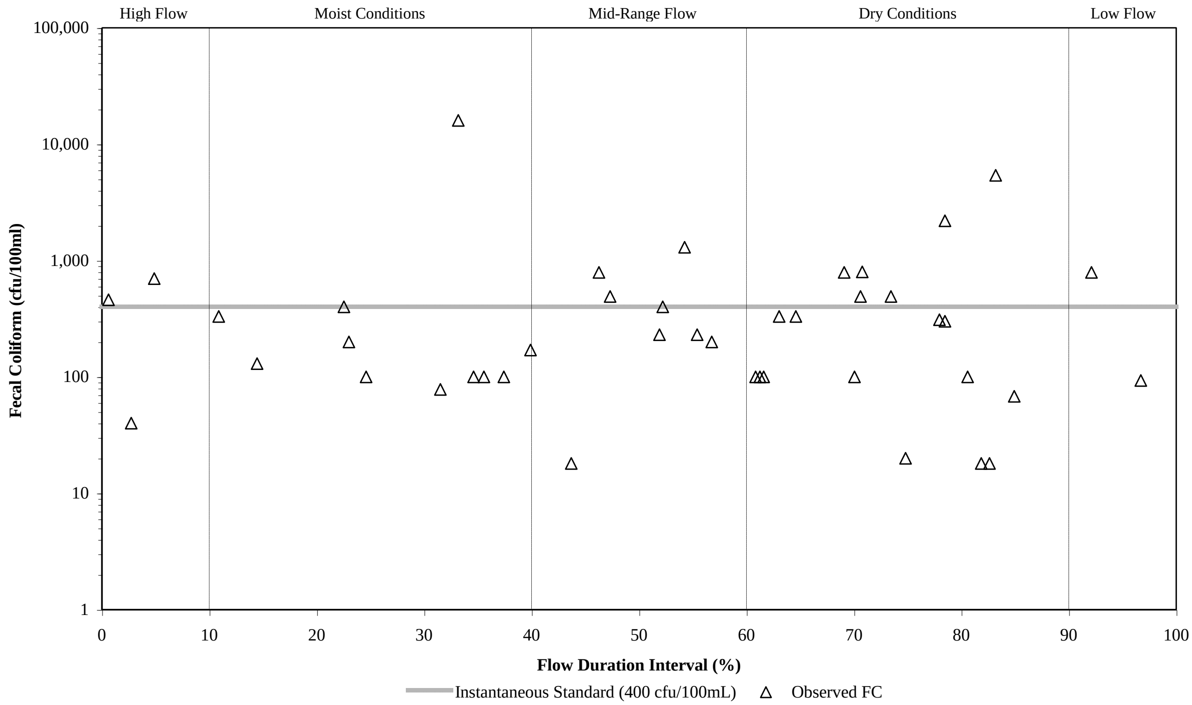

Figure B.56 Fecal coliform concentrations at 2-TKO010.64 in Tuckahoe Creek versus discharge at USGS Gaging Station #02037500.

Trend and Seasonal Analyses

Table B. 1 Summary of fecal coliform data trends at VADEQ stations (cfu/100mL).

Stream	Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]	p-value
Almond Creek	2-ALM000.42	1,946	445	16,000	20	3,112	192	-9.524	0.024
Bernards Creek	2-BOR001.73	647	100	7,100	18	1,628	36	--	
Falling Creek	2-FAC000.85	348	100	16,000	8	1,347	222	No Trend	
Gillie Creek	2-GIL000.42	1,898	400	8,000	100	2,755	81	No Trend	
Gillie Creek	2-GIL000.03	9,073	6,000	60,000	300	14,473	15	--	
Grindall Creek	2-GRK000.57	1,461	600	8,000	100	2,162	106	No Trend	
James River	2-JMS117.35	944	200	16,000	18	2,383	776	<0.001	<0.001
James River	2-JMS104.16	690	100	16,000	18	2,029	155	-5.882	0.015
James River	2-JMS099.30	1,363	130	47,325	17	4,465	183	-6.667	<0.001
James River	2-JMS097.77	2,796	225	80,000	10	10,674	58	--	
James River	2-JMS097.41	835	175	8,245	10	1,900	44	--	
James River	2-JMS087.01	507	100	16,000	18	1,645	170	-1.757	0.005
James River	2-JMS078.99	982	100	8,245	9	2,089	69	--	
Powhite Creek	2-PWT000.57	719	200	16,000	18	1,685	153	No Trend	
Proctors Creek	2-PCT002.46	655	200	8,000	100	1,258	104	No Trend	
Reedy Creek	2-RDD000.76	2,597	1,300	16,000	46	3,709	105	No Trend	
Tuckahoe Creek	2-TKO004.69	820	130	16,000	18	2,592	89	--	

[1]SD: standard deviation, [2]N: number of sample measurements, [3]A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--" insufficient data

Table B. 2 Summary of the Mood's Median Test on fecal coliform data from VADEQ station 2-JMS117.35 (p=0.003).

Month	Mean (in)	Minimum (in)	Maximum (in)	Median Groups	
January	722	18	16,000	A	B
February	497	25	8,000	A	B
March	729	18	16,000	A	
April	1,133	20	16,000	A	B
May	769	18	8,000	A	B
June	1,365	20	16,000	A	B
July	1,157	20	16,000		B
August	1,700	20	16,000	A	B
September	1,096	18	16,000	A	B
October	618	25	6,500	A	B
November	749	18	16,000	A	
December	860	18	16,000	A	B

Table B. 3 Summary of the Mood's Median Test on fecal coliform data from VADEQ station 2-JMS087.01 (p=0.039).

Month	Mean (in)	Minimum (in)	Maximum (in)	Median Groups	
January	1,625	45	16,000	A	B
February	300	20	2,200	A	
March	291	18	1,500	A	B
April	101	18	320	A	B
May	802	25	7,550	A	
June	163	24	1,260	A	B
July	166	18	700	A	B
August	239	25	1,106	A	B
September	494	25	5,540	A	B
October	770	25	5,520	A	B
November	192	18	620	A	B
December	1,217	100	9,200		B

Table B. 4 Summary of the Mood's Median Test on fecal coliform data from VADEQ station 2-PWT000.57 (p=0.005).

Month	Mean (in)	Minimum (in)	Maximum (in)	Median Groups	
January	220	45	1,100	A	B
February	342	100	1,600	A	
March	345	78	3,500	A	
April	360	100	1,200	A	B
May	874	100	5,200	A	B
June	600	100	1,900	A	B
July	525	100	1,700		B
August	1,367	100	3,500	A	B
September	1,848	100	16,000		B
October	975	100	6,500	A	B
November	642	18	6,800	A	
December	600	100	4,200	A	B

Table B. 5 Summary of the Mood's Median Test on precipitation data from NCDC station 447201 Richmond/Byrd Airport (p=0.001).

Month	Mean (in)	Minimum (in)	Maximum (in)	Median Groups	
January	3.12	0.64	7.97	A	B
February	2.94	0.48	5.97	A	B
March	3.73	0.2	8.65	A	B
April	2.97	0.64	7.31	A	
May	3.65	0.87	8.87	A	B
June	3.66	0.38	8.82	A	B
July	5.02	0.51	13.90		B
August	4.80	0.81	14.62		B
September	3.71	0.08	15.10	A	B
October	3.35	0.01	9.39	A	B
November	3.21	0.17	7.64	A	B
December	3.20	0.4	7.07	A	B

Box and Whisker Plots

Interpretation of box and whisker plots is illustrated in Figure B.57, in which the data range for a given metric is displayed as four quartiles. The "box" of two colors shows the two inner quartiles with the dividing line between the colors representing the median value. The "whiskers" above and below each box show the outer quartiles with the upper quartile extending above the box and the lower quartile extending below the box. Finally, the mean value is displayed as a square within one of the two inner-quartile boxes.

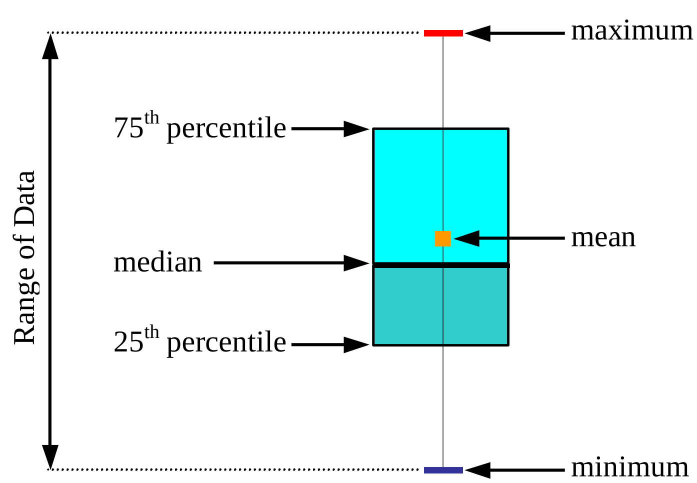

Figure B.57 Interpretation of Box and Whisker plots.

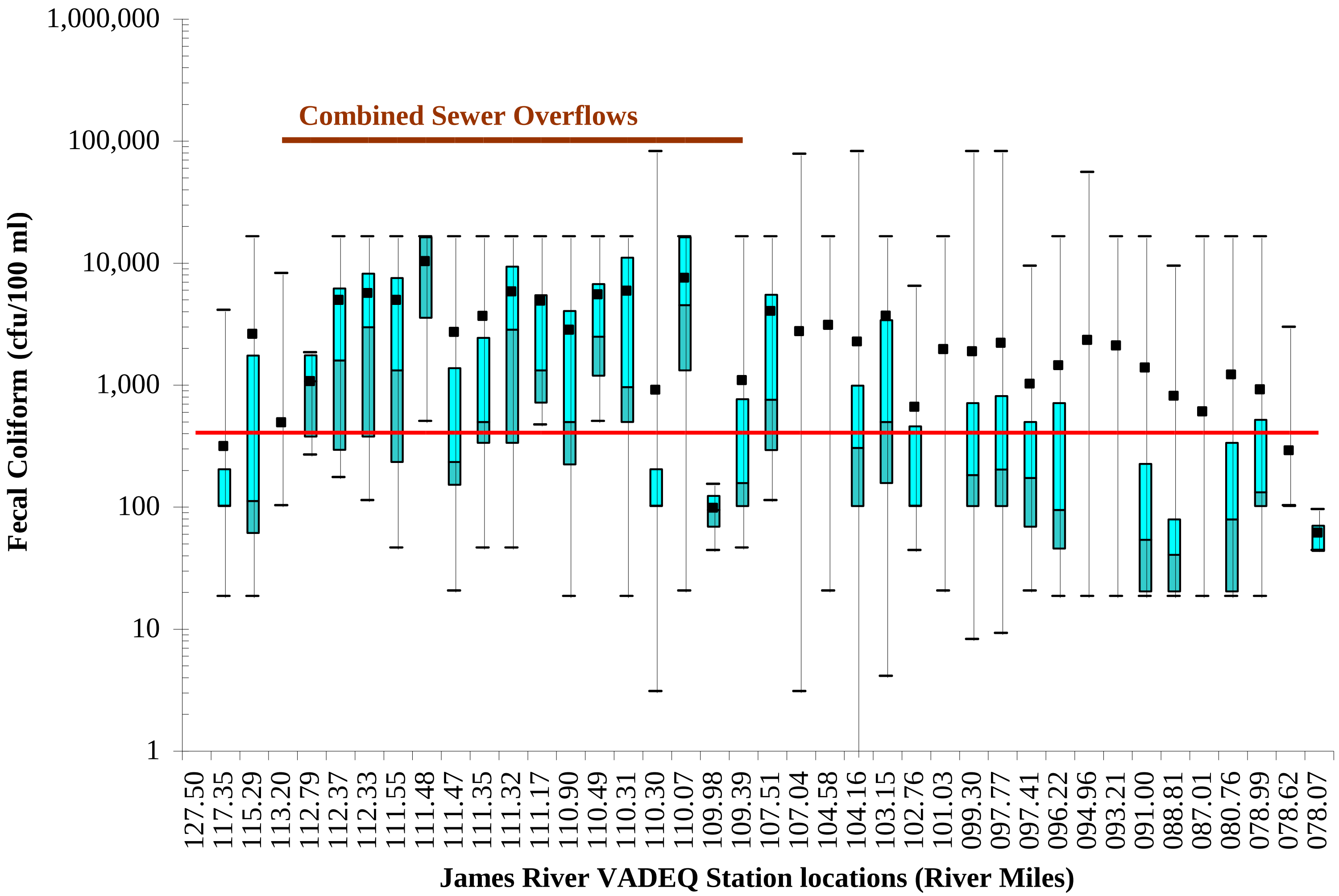

Figure B.58 Fecal coliform data from 1970 through 1995 from VADEQ stations on the James River arranged upstream to downstream.

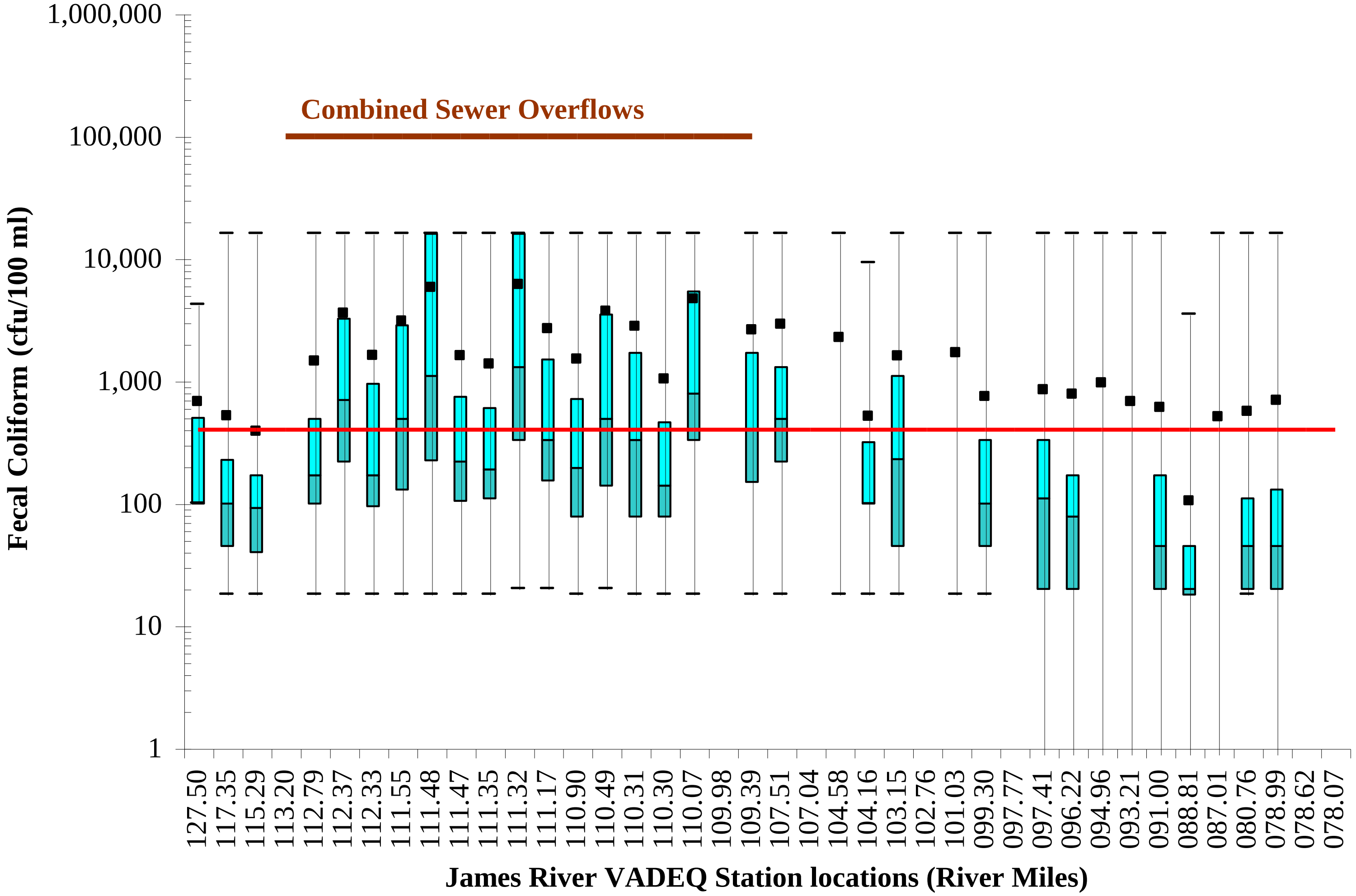

Figure B.59 Fecal coliform data from 1996 through 2003 from VADEQ stations on the James River arranged upstream to downstream.

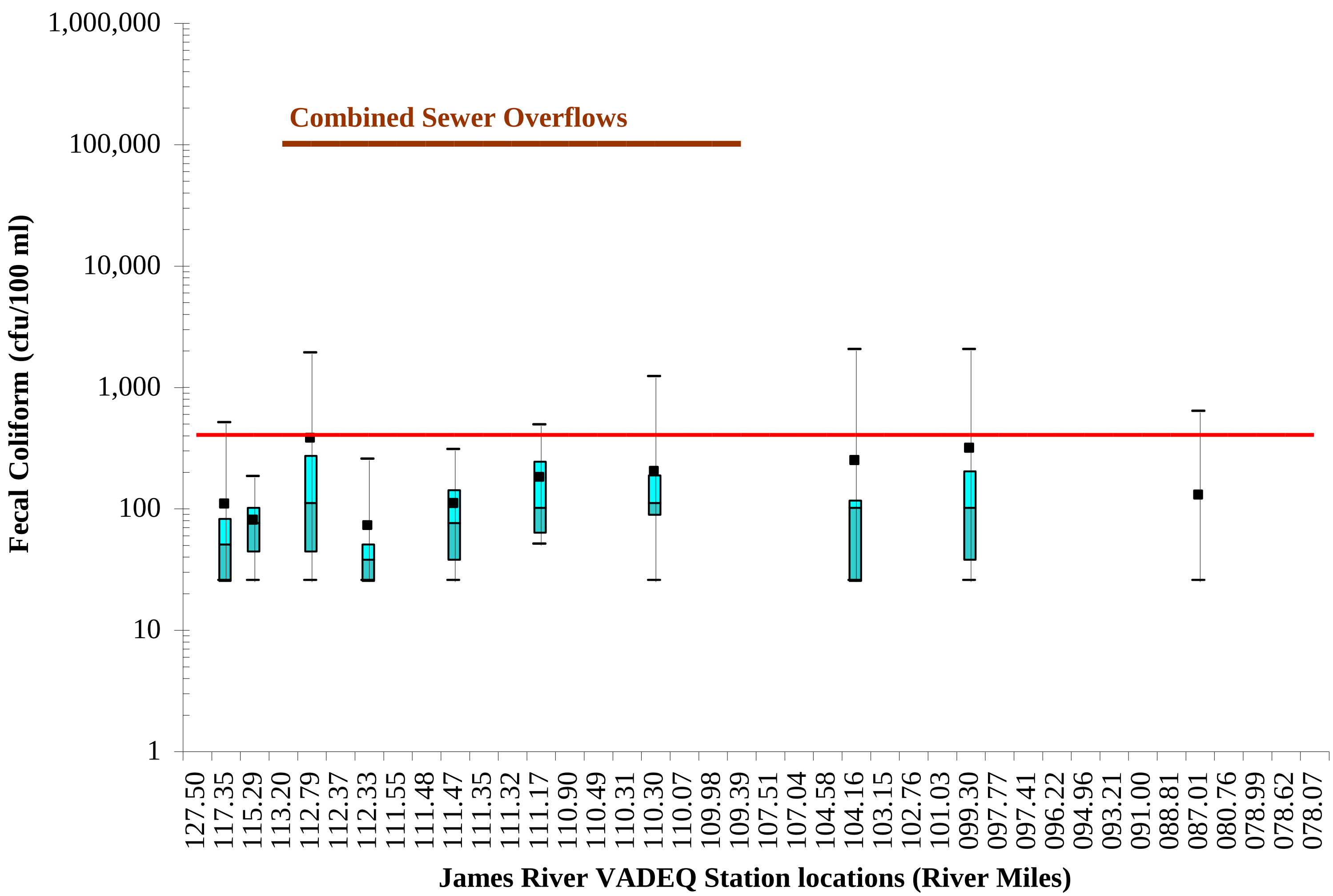

Figure B.60 **Fecal coliform data from 2004 through 2007 from VADEQ stations on the James River arranged upstream to downstream.**

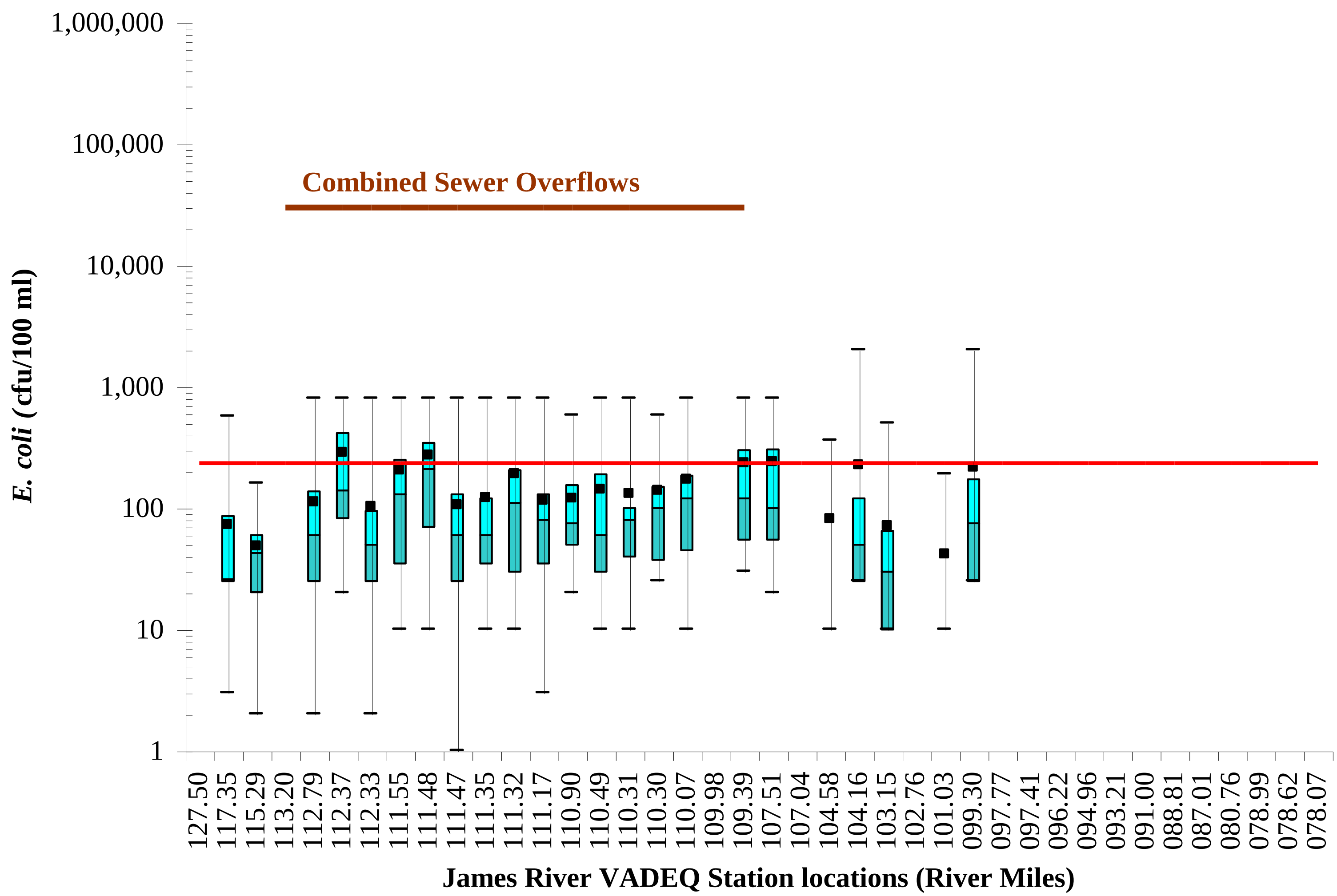

Figure B.61 ***E. coli*** **data from 2000 through 2006 from VADEQ stations on the James River arranged upstream to downstream.**

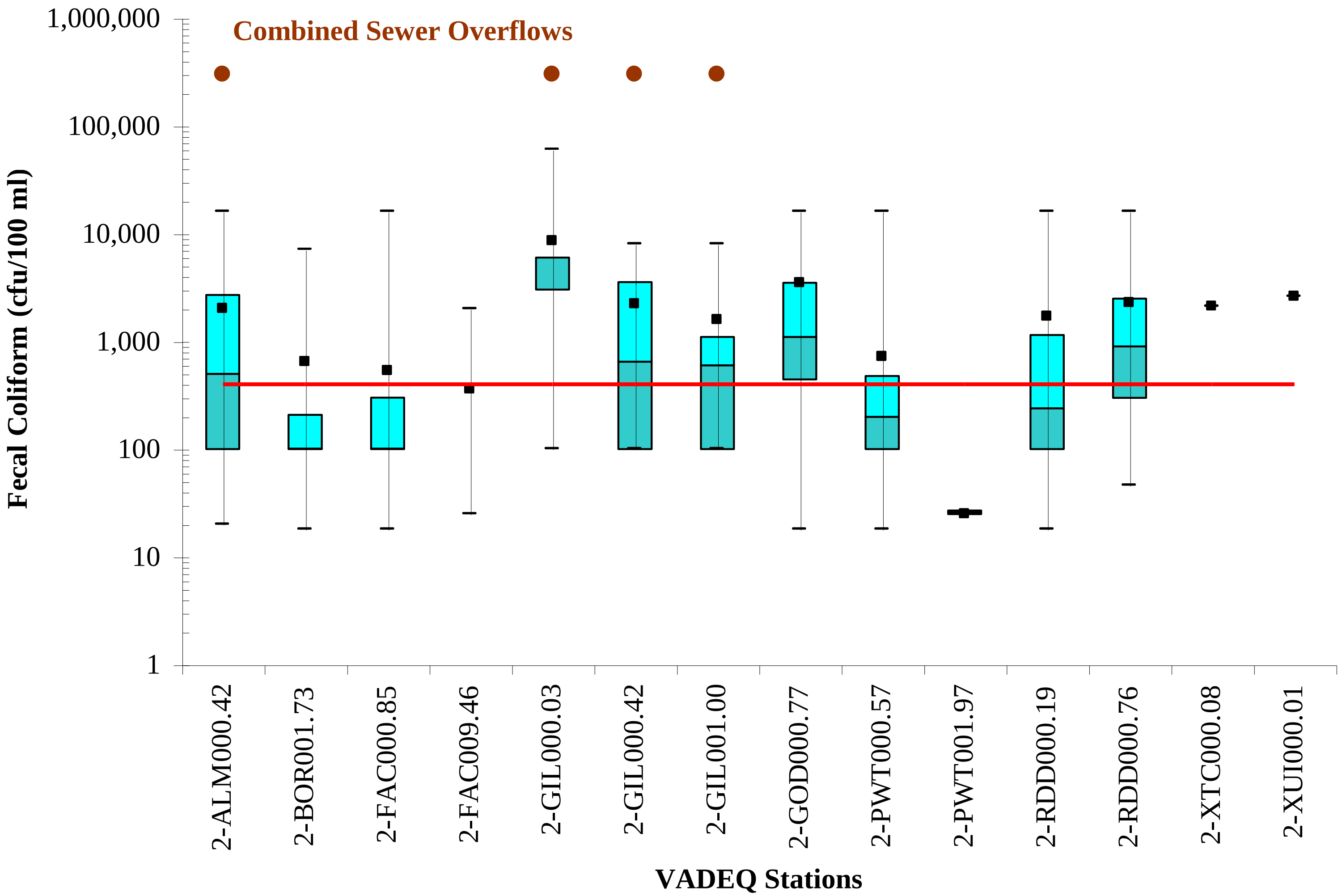

Figure B.62 Fecal coliform data from VADEQ stations on the James River tributary impairments.

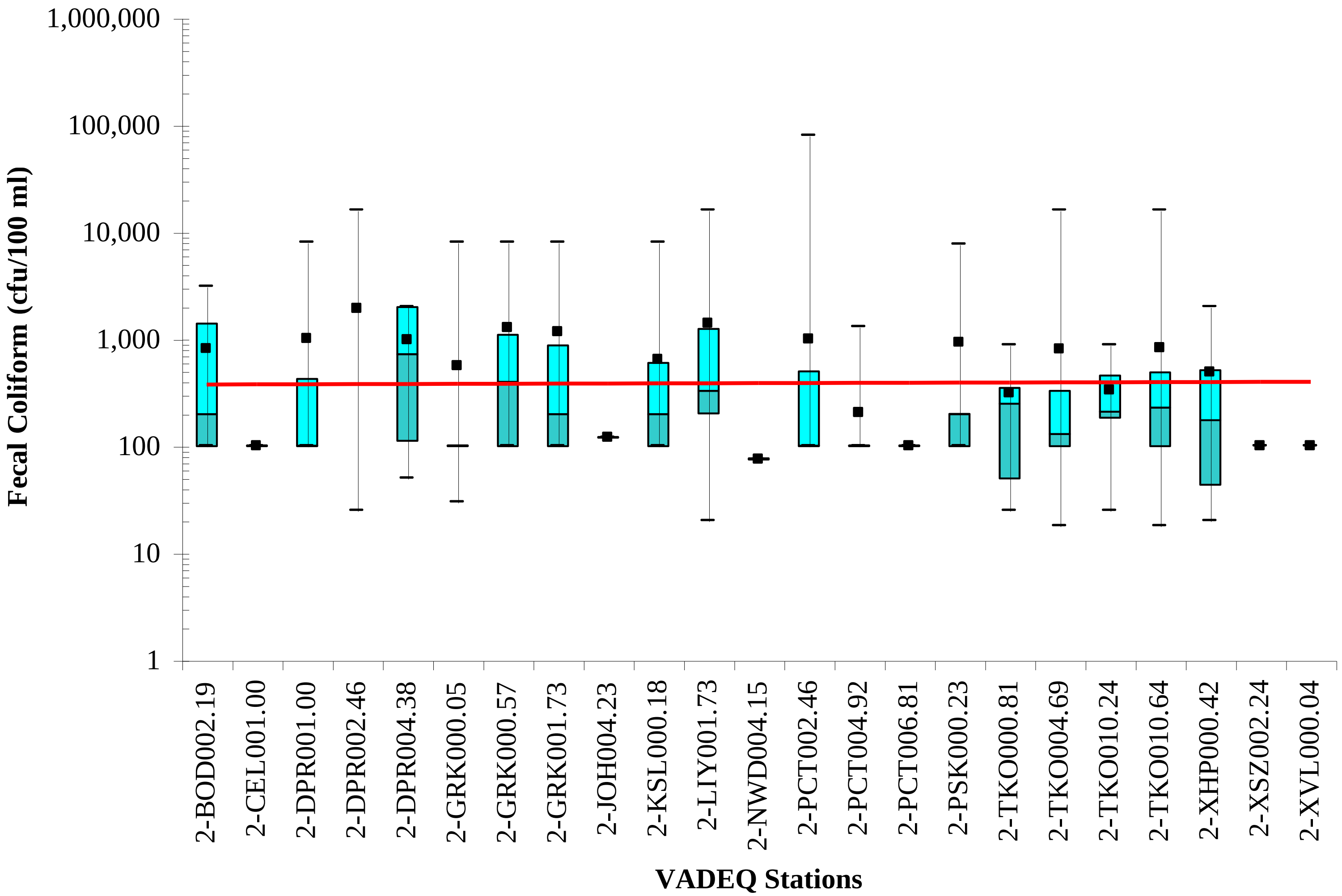

Figure B.63 Fecal coliform data from VADEQ stations on the James River tributary non-impaired segments.

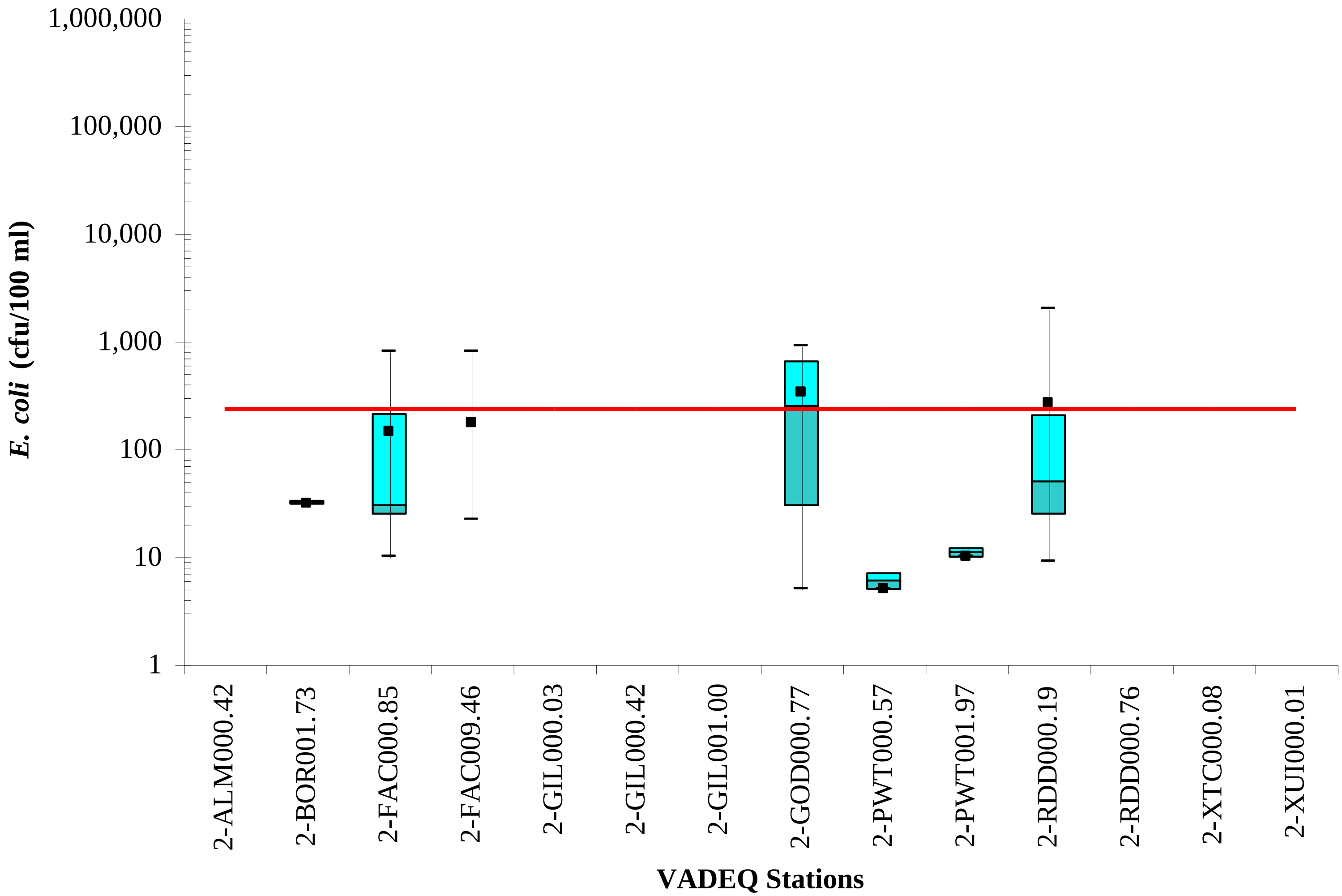

Figure B.64 ***E. coli*** **data from VADEQ stations on the James River tributary impairments.**

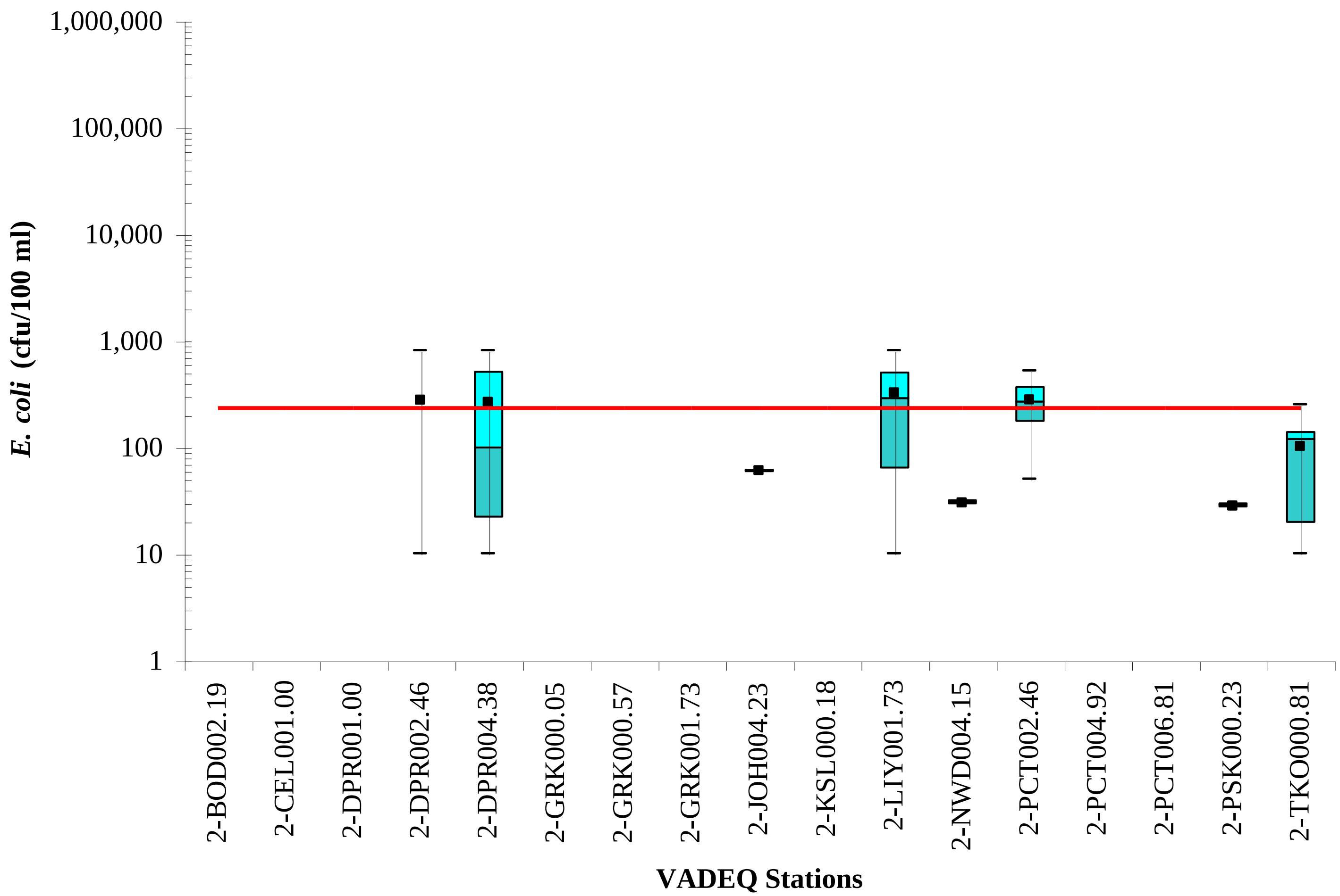

Figure B.65 ***E. coli*** **data from VADEQ stations on the James River tributary non-impaired segments.**

APPENDIX C: LAND-BASED FECAL COLIFORM LOADS FOR EXISTING CONDITIONS

Almond Creek

Table C.1 Current conditions of land applied fecal coliform load for Almond Creek by land use (subwatersheds 18, 52).

Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	3.72E+10	3.36E+10	3.72E+10	3.60E+10	3.72E+10	3.60E+10	3.72E+10	3.72E+10	3.60E+10	3.72E+10	3.60E+10	3.72E+10	4.38E+11
Commercial	3.53E+10	3.19E+10	3.53E+10	3.41E+10	3.53E+10	3.41E+10	3.53E+10	3.53E+10	3.41E+10	3.53E+10	3.41E+10	3.53E+10	4.15E+11
Cropland	1.39E+11	1.25E+11	1.39E+11	1.34E+11	1.39E+11	1.34E+11	1.39E+11	1.39E+11	1.34E+11	1.39E+11	1.34E+11	1.39E+11	1.64E+12
Forest	1.27E+12	1.15E+12	1.27E+12	1.23E+12	1.27E+12	1.23E+12	1.27E+12	1.27E+12	1.23E+12	1.27E+12	1.23E+12	1.27E+12	1.50E+13
LAX	5.84E+10	5.27E+10	8.32E+10	1.12E+11	1.16E+11	1.36E+11	1.41E+11	1.41E+11	1.12E+11	8.32E+10	8.05E+10	5.84E+10	1.18E+12
LMIR	1.34E+13	1.21E+13	1.33E+13	1.29E+13	1.33E+13	1.28E+13	1.31E+13	1.31E+13	1.27E+13	1.31E+13	1.27E+13	1.33E+13	1.56E+14
Open Space	3.51E+11	3.17E+11	3.51E+11	3.39E+11	3.51E+11	3.39E+11	3.51E+11	3.51E+11	3.39E+11	3.51E+11	3.39E+11	3.51E+11	4.13E+12
PastureHay	5.38E+12	4.86E+12	5.34E+12	5.12E+12	5.29E+12	5.09E+12	5.26E+12	5.26E+12	5.12E+12	5.34E+12	5.17E+12	5.38E+12	6.26E+13
Wetland	1.23E+11	1.11E+11	1.23E+11	1.19E+11	1.23E+11	1.19E+11	1.23E+11	1.23E+11	1.19E+11	1.23E+11	1.19E+11	1.23E+11	1.45E+12

Table C.2 Monthly, directly deposited fecal coliform loads in Almond Creek (reaches 18, 52).

Source Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human	5.49E+11	4.96E+11	5.49E+11	5.31E+11	5.49E+11	5.31E+11	5.49E+11	5.49E+11	5.31E+11	5.49E+11	5.31E+11	5.49E+11	6.47E+12
Livestock	2.48E+10	2.24E+10	3.54E+10	4.80E+10	4.96E+10	5.83E+10	6.02E+10	6.02E+10	4.80E+10	3.54E+10	3.43E+10	2.48E+10	5.01E+11
Wildlife	3.02E+10	2.73E+10	3.02E+10	2.93E+10	3.02E+10	2.93E+10	3.02E+10	3.02E+10	2.93E+10	3.02E+10	2.93E+10	3.02E+10	3.56E+11

Table C.3 Existing annual loads from land-based sources for Almond Creek (subwatersheds 18, 52).

Source	Barren	Commercial	Cropland	Forest	LAX	LMIR	OpenSpace	PastureHay	Wetland
Beef	0	0	0	0	8.37E+11	0	0	2.27E+13	0
Beef Calf	0	0	0	0	3.32E+11	0	0	9.01E+12	0
Cats	0	0	0	0	0	1.29E+08	0	0	0
Dairy	0	0	0	0	0	0	0	0	0
Dairy Calf	0	0	0	0	0	0	0	0	0
Dairy Dry	0	0	0	0	0	0	0	0	0
Deer	0	0	5.83E+11	3.22E+12	2.87E+08	5.73E+11	5.73E+11	2.67E+12	2.78E+11
Dogs	0	0	0	0	0	1.42E+14	0	0	0
Duck	2.64E+06	2.14E+07	0	6.55E+08	8.91E+05	1.57E+08	7.22E+07	2.18E+07	3.07E+07
Goose	1.70E+08	1.38E+09	0	4.23E+10	5.75E+07	1.01E+10	4.66E+09	1.41E+09	1.98E+09
Hogs	0	0	0	0	0	0	0	7.48E+11	0
Horse	0	0	0	0	0	0	0	2.38E+13	0
Muskrat	1.74E+10	1.41E+11	0	4.32E+12	5.88E+09	1.03E+12	4.76E+11	1.44E+11	2.03E+11
People w/Septic Failures	0	0	0	0	0	7.98E+12	0	0	0
Raccoon	4.21E+11	2.73E+11	1.05E+12	7.38E+12	0	3.99E+12	3.07E+12	3.45E+12	9.63E+11
Sheep	0	0	0	0	0	0	0	1.03E+11	0
Turkey	0	0	6.51E+07	1.44E+09	3.20E+04	0	0	2.98E+08	1.24E+08

Table C.4 Existing annual loads from direct-deposition sources for Almond Creek (reaches 18, 52).

Source	Annual Total Loads (cfu/yr)
Beaver	3.29E+03
Beef	3.59E+11
Beef Calf	1.42E+11
Dairy	0
Dairy Calf	0
Dairy Dry	0
Deer	3.95E+09
Duck	3.75E+07
Goose	1.59E+09
Hogs	0
Horse	0
Muskrat	2.99E+11
People w/Straight Pipes	6.47E+12
Raccoon	5.16E+10
Sheep	0
Turkey	9.63E+05

Bernards Creek

Table C.5 Current conditions of land applied fecal coliform load for Bernards Creek by land use (subwatershed 16).

Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	0	0	0	0	0	0	0	0	0	0	0	0	0
Commercial	3.19E+09	2.88E+09	3.19E+09	3.08E+09	3.19E+09	3.08E+09	3.19E+09	3.19E+09	3.08E+09	3.19E+09	3.08E+09	3.19E+09	3.75E+10
Cropland	1.52E+12	1.48E+12	1.18E+13	1.18E+13	3.24E+12	3.63E+11	3.76E+11	3.76E+11	1.24E+13	1.18E+13	1.51E+12	1.52E+12	5.82E+13
Forest	7.99E+12	7.22E+12	7.99E+12	7.73E+12	7.99E+12	7.73E+12	7.99E+12	7.99E+12	7.73E+12	7.99E+12	7.73E+12	7.99E+12	9.41E+13
LAX	3.41E+11	3.08E+11	4.60E+11	5.90E+11	6.10E+11	7.06E+11	7.29E+11	7.29E+11	5.90E+11	4.60E+11	4.46E+11	3.41E+11	6.31E+12
LMIR	9.54E+12	8.56E+12	9.38E+12	1.83E+13	9.27E+12	8.92E+12	9.11E+12	9.11E+12	8.82E+12	9.06E+12	8.82E+12	9.32E+12	1.18E+14
Open Space	1.48E+12	1.33E+12	1.48E+12	1.43E+12	1.48E+12	1.43E+12	1.48E+12	1.48E+12	1.43E+12	1.48E+12	1.43E+12	1.48E+12	1.74E+13
PastureHay	1.69E+13	1.52E+13	1.67E+13	1.60E+13	1.65E+13	1.69E+13	1.75E+13	1.75E+13	1.60E+13	1.67E+13	1.62E+13	1.69E+13	1.99E+14
Wetland	2.69E+12	2.43E+12	2.69E+12	2.60E+12	2.69E+12	2.60E+12	2.69E+12	2.69E+12	2.60E+12	2.69E+12	2.60E+12	2.69E+12	3.17E+13

Table C.6 Monthly, directly deposited fecal coliform loads in Bernards Creek (reach 16).

Source Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human	8.24E+11	7.44E+11	8.24E+11	7.97E+11	8.24E+11	7.97E+11	8.24E+11	8.24E+11	7.97E+11	8.24E+11	7.97E+11	8.24E+11	9.70E+12
Livestock	9.12E+10	8.24E+10	1.42E+11	2.00E+11	2.06E+11	2.49E+11	2.58E+11	2.58E+11	2.00E+11	1.42E+11	1.38E+11	9.12E+10	2.06E+12
Wildlife	2.08E+11	1.88E+11	2.08E+11	2.01E+11	2.08E+11	2.01E+11	2.08E+11	2.08E+11	2.01E+11	2.08E+11	2.01E+11	2.08E+11	2.45E+12

Table C.7 Existing annual loads from land-based sources for Bernards Creek (subwatershed 16).

Source	Barren	Commercial	Cropland	Forest	LAX	LMIR	OpenSpace	PastureHay	Wetland
Beef	0	0	0	0	2.57E+12	0	0	6.97E+13	0
Beef Calf	0	0	0	0	7.39E+11	0	0	2.00E+13	0
Cats	0	0	0	0	0	8.64E+07	0	0	0
Dairy	0	0	4.83E+13	0	0	0	0	3.08E+12	0
Dairy Calf	0	0	5.51E+12	0	0	0	0	3.52E+11	0
Dairy Dry	0	0	0	0	1.49E+12	0	0	2.62E+13	0
Deer	0	0	8.35E+11	2.31E+13	9.98E+10	2.09E+11	1.45E+12	3.41E+12	2.15E+12
Dogs	0	0	0	0	0	9.54E+13	0	0	0
Duck	0	0	1.67E+08	2.56E+09	1.64E+08	3.20E+07	6.32E+08	3.95E+08	3.08E+09
Goose	0	0	1.05E+10	1.62E+11	1.03E+10	2.02E+09	3.99E+10	2.49E+10	1.94E+11
Hogs	0	0	0	0	0	0	0	3.74E+12	0
Horse	0	0	0	0	0	0	0	6.11E+13	0
Muskrat	0	0	1.10E+12	1.69E+13	1.08E+12	2.11E+11	4.17E+12	2.61E+12	2.03E+13
People w/Septic Failures	0	0	0	0	0	2.09E+13	0	0	0
Raccoon	0	3.75E+10	2.48E+12	5.40E+13	3.23E+11	1.44E+12	1.17E+13	8.53E+12	9.01E+12
Sheep	0	0	0	0	0	0	0	6.83E+10	0
Turkey	0	0	9.90E+07	1.10E+10	1.18E+07	0	0	4.04E+08	1.02E+09

Table C.8 Existing annual loads from direct-deposition sources for Bernards Creek (reach 16).

Source	Annual Total Loads (cfu/yr)
Beaver	2.45E+04
Beef	1.10E+12
Beef Calf	3.17E+11
Dairy	0
Dairy Calf	0
Dairy Dry	6.39E+11
Deer	1.56E+10
Duck	2.76E+08
Goose	1.15E+10
Hogs	0
Horse	0
Muskrat	2.20E+12
People w/Straight Pipes	9.70E+12
Raccoon	2.19E+11
Sheep	0
Turkey	6.25E+06

Falling Creek

Table C.9 Current conditions of land applied fecal coliform load for Falling Creek by land use (subwatersheds 20, 21, 22).

Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	3.87E+10	3.50E+10	3.87E+10	3.75E+10	3.87E+10	3.75E+10	3.87E+10	3.87E+10	3.75E+10	3.87E+10	3.75E+10	3.87E+10	4.56E+11
Commercial	2.64E+11	2.38E+11	2.64E+11	2.55E+11	2.64E+11	2.55E+11	2.64E+11	2.64E+11	2.55E+11	2.64E+11	2.55E+11	2.64E+11	3.11E+12
Cropland	3.71E+11	3.35E+11	3.71E+11	3.59E+11	3.71E+11	3.59E+11	3.71E+11	3.71E+11	3.59E+11	3.71E+11	3.59E+11	3.71E+11	4.37E+12
Forest	1.86E+13	1.68E+13	1.86E+13	1.80E+13	1.86E+13	1.80E+13	1.86E+13	1.86E+13	1.80E+13	1.86E+13	1.80E+13	1.86E+13	2.19E+14
LAX	2.71E+11	2.44E+11	3.61E+11	4.65E+11	4.80E+11	5.52E+11	5.70E+11	5.70E+11	4.65E+11	3.61E+11	3.49E+11	2.71E+11	4.96E+12
LMIR	1.72E+14	1.55E+14	1.72E+14	1.66E+14	1.71E+14	1.66E+14	1.71E+14	1.71E+14	1.65E+14	1.71E+14	1.65E+14	1.72E+14	2.02E+15
Open Space	9.44E+12	8.53E+12	9.44E+12	9.14E+12	9.44E+12	9.14E+12	9.44E+12	9.44E+12	9.14E+12	9.44E+12	9.14E+12	9.44E+12	1.11E+14
PastureHay	2.59E+13	2.34E+13	2.58E+13	2.48E+13	2.56E+13	2.46E+13	2.55E+13	2.55E+13	2.48E+13	2.58E+13	2.49E+13	2.59E+13	3.02E+14
Wetland	3.13E+12	2.83E+12	3.13E+12	3.03E+12	3.13E+12	3.03E+12	3.13E+12	3.13E+12	3.03E+12	3.13E+12	3.03E+12	3.13E+12	3.69E+13

Table C.10 Monthly, directly deposited fecal coliform loads in Falling Creek (reaches 20, 21, 22).

Source Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human	1.65E+12	1.49E+12	1.65E+12	1.59E+12	1.65E+12	1.59E+12	1.65E+12	1.65E+12	1.59E+12	1.65E+12	1.59E+12	1.65E+12	1.94E+13
Livestock	8.99E+10	8.11E+10	1.28E+11	1.74E+11	1.80E+11	2.11E+11	2.19E+11	2.19E+11	1.74E+11	1.28E+11	1.24E+11	8.99E+10	1.82E+12
Wildlife	6.27E+11	5.67E+11	6.27E+11	6.07E+11	6.27E+11	6.07E+11	6.27E+11	6.27E+11	6.07E+11	6.27E+11	6.07E+11	6.27E+11	7.40E+12

Table C.11 Existing annual loads from land-based sources for Falling Creek (subwatersheds 20, 21, 22).

Source	Barren	Commercial	Cropland	Forest	LAX	LMIR	OpenSpace	PastureHay	Wetland
Beef	0	0	0	0	3.38E+12	0	0	9.15E+13	0
Beef Calf	0	0	0	0	8.62E+11	0	0	2.33E+13	0
Cats	0	0	0	0	0	1.75E+09	0	0	0
Dairy	0	0	0	0	0	0	0	0	0
Dairy Calf	0	0	0	0	0	0	0	0	0
Dairy Dry	0	0	0	0	0	0	0	0	0
Deer	0	0	1.25E+12	4.69E+13	5.79E+10	5.57E+12	1.18E+13	4.51E+12	3.74E+12
Dogs	0	0	0	0	0	1.93E+15	0	0	0
Duck	2.14E+07	1.36E+08	1.27E+08	1.14E+10	8.06E+07	1.98E+09	4.15E+09	3.24E+08	3.09E+09
Goose	1.38E+09	8.81E+09	8.22E+09	7.35E+11	5.20E+09	1.28E+11	2.68E+11	2.09E+10	2.00E+11
Hogs	0	0	0	0	0	0	0	2.32E+13	0
Horse	0	0	0	0	0	0	0	1.49E+14	0
Muskrat	1.41E+11	9.00E+11	8.40E+11	7.51E+13	5.32E+11	1.31E+13	2.73E+13	2.14E+12	2.04E+13
People w/Septic Failures	0	0	0	0	0	3.64E+13	0	0	0
Raccoon	3.13E+11	2.20E+12	2.26E+12	9.61E+13	1.23E+11	3.39E+13	7.18E+13	8.27E+12	1.25E+13
Sheep	0	0	0	0	0	0	0	1.71E+11	0
Turkey	0	0	1.40E+08	2.10E+10	6.46E+06	0	0	5.04E+08	1.67E+09

Table C.12 Existing annual loads from direct-deposition sources for Falling Creek (reaches 20, 21, 22).

Source	Annual Total Loads (cfu/yr)
Beaver	7.41E+04
Beef	1.45E+12
Beef Calf	3.69E+11
Dairy	0
Dairy Calf	0
Dairy Dry	0
Deer	3.69E+10
Duck	8.46E+08
Goose	3.59E+10
Hogs	0
Horse	0
Muskrat	6.75E+12
People w/Straight Pipes	1.94E+13
Raccoon	5.71E+11
Sheep	0
Turkey	1.16E+07

Gillie Creek

Table C.13 Current conditions of land applied fecal coliform load for Gillie Creek by land use (subwatersheds 40, 63- 68, 71, 79).

Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	7.35E+10	6.64E+10	7.35E+10	7.12E+10	7.35E+10	7.12E+10	7.35E+10	7.35E+10	7.12E+10	7.35E+10	7.12E+10	7.35E+10	8.66E+11
Commercial	6.05E+10	5.46E+10	6.05E+10	5.85E+10	6.05E+10	5.85E+10	6.05E+10	6.05E+10	5.85E+10	6.05E+10	5.85E+10	6.05E+10	7.12E+11
Cropland	2.35E+11	2.12E+11	2.35E+11	2.28E+11	2.35E+11	2.28E+11	2.35E+11	2.35E+11	2.28E+11	2.35E+11	2.28E+11	2.35E+11	2.77E+12
Forest	3.61E+12	3.26E+12	3.61E+12	3.50E+12	3.61E+12	3.50E+12	3.61E+12	3.61E+12	3.50E+12	3.61E+12	3.50E+12	3.61E+12	4.25E+13
LAX	9.41E+10	8.50E+10	1.28E+11	1.69E+11	1.74E+11	2.02E+11	2.09E+11	2.09E+11	1.69E+11	1.28E+11	1.24E+11	9.41E+10	1.78E+12
LMIR	6.59E+13	5.95E+13	6.57E+13	6.35E+13	6.55E+13	6.33E+13	6.53E+13	6.53E+13	6.32E+13	6.52E+13	6.32E+13	6.56E+13	7.71E+14
Open Space	1.50E+12	1.36E+12	1.50E+12	1.45E+12	1.50E+12	1.45E+12	1.50E+12	1.50E+12	1.45E+12	1.50E+12	1.45E+12	1.50E+12	1.77E+13
PastureHay	7.30E+12	6.59E+12	7.25E+12	6.95E+12	7.18E+12	6.90E+12	7.13E+12	7.13E+12	6.95E+12	7.25E+12	7.01E+12	7.30E+12	8.49E+13
Wetland	2.54E+11	2.30E+11	2.54E+11	2.46E+11	2.54E+11	2.46E+11	2.54E+11	2.54E+11	2.46E+11	2.54E+11	2.46E+11	2.54E+11	3.00E+12

Table C.14 Monthly, directly deposited fecal coliform loads in Gillie Creek (reaches 40, 63- 68, 71, 79).

Source Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human	4.76E+12	4.30E+12	4.76E+12	4.60E+12	4.76E+12	4.60E+12	4.76E+12	4.76E+12	4.60E+12	4.76E+12	4.60E+12	4.76E+12	5.61E+13
Livestock	3.53E+10	3.18E+10	5.04E+10	6.82E+10	7.05E+10	8.29E+10	8.57E+10	8.57E+10	6.82E+10	5.04E+10	4.87E+10	3.53E+10	7.13E+11
Wildlife	9.73E+10	8.79E+10	9.73E+10	9.41E+10	9.73E+10	9.41E+10	9.73E+10	9.73E+10	9.41E+10	9.73E+10	9.41E+10	9.73E+10	1.14E+12

Table C.15 Existing annual loads from land-based sources for Gillie Creek (subwatersheds 40, 63- 68, 71, 79).

Source	Barren	Commercial	Cropland	Forest	LAX	LMIR	OpenSpace	PastureHay	Wetland
Beef	0	0	0	0	1.17E+12	0	0	3.16E+13	0
Beef Calf	0	0	0	0	4.56E+11	0	0	1.23E+13	0
Cats	0	0	0	0	0	6.68E+08	0	0	0
Dairy	0	0	0	0	0	0	0	0	0
Dairy Calf	0	0	0	0	0	0	0	0	0
Dairy Dry	0	0	0	0	0	0	0	0	0
Deer	0	0	9.97E+11	9.65E+12	7.23E+09	2.21E+12	2.33E+12	2.80E+12	4.96E+11
Dogs	0	0	0	0	0	7.38E+14	0	0	0
Duck	4.80E+07	4.01E+06	2.74E+07	1.98E+09	1.97E+07	4.58E+08	5.52E+08	2.91E+07	1.14E+08
Goose	3.10E+09	2.59E+08	1.77E+09	1.28E+11	1.27E+09	2.96E+10	3.56E+10	1.88E+09	7.38E+09
Hogs	0	0	0	0	0	0	0	1.50E+12	0
Horse	0	0	0	0	0	0	0	3.25E+13	0
Muskrat	3.16E+11	2.65E+10	1.81E+11	1.30E+13	1.30E+11	3.02E+12	3.64E+12	1.92E+11	7.54E+11
People w/Septic Failures	0	0	0	0	0	1.67E+13	0	0	0
Raccoon	5.46E+11	6.85E+11	1.59E+12	1.97E+13	2.45E+10	1.11E+13	1.17E+13	3.83E+12	1.74E+12
Sheep	0	0	0	0	0	0	0	1.54E+11	0
Turkey	0	0	1.11E+08	4.31E+09	8.07E+05	0	0	3.12E+08	2.21E+08

Table C.16 Existing annual loads from direct-deposition sources for Gillie Creek (reaches 40, 63- 68, 71, 79).

Source	Annual Total Loads (cfu/yr)
Beaver	3.65E+02
Beef	5.13E+11
Beef Calf	2.01E+11
Dairy	0
Dairy Calf	0
Dairy Dry	0
Deer	9.25E+09
Duck	1.26E+08
Goose	5.35E+09
Hogs	0
Horse	0
Muskrat	1.00E+12
People w/Straight Pipes	5.60E+13
Raccoon	1.28E+11
Sheep	0
Turkey	2.48E+06

Goode Creek

Table C.17 Current conditions of land applied fecal coliform load for Goode Creek by land use (subwatershed 19).

Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	9.08E+09	8.20E+09	9.08E+09	8.79E+09	9.08E+09	8.79E+09	9.08E+09	9.08E+09	8.79E+09	9.08E+09	8.79E+09	9.08E+09	1.07E+11
Commercial	1.39E+11	1.25E+11	1.39E+11	1.34E+11	1.39E+11	1.34E+11	1.39E+11	1.39E+11	1.34E+11	1.39E+11	1.34E+11	1.39E+11	1.63E+12
Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
Forest	7.38E+11	6.66E+11	7.38E+11	7.14E+11	7.38E+11	7.14E+11	7.38E+11	7.38E+11	7.14E+11	7.38E+11	7.14E+11	7.38E+11	8.69E+12
LAX	0	0	0	0	0	0	0	0	0	0	0	0	0
LMIR	2.89E+13	2.61E+13	2.89E+13	2.80E+13	2.89E+13	2.79E+13	2.89E+13	2.89E+13	2.79E+13	2.89E+13	2.79E+13	2.89E+13	3.40E+14
Open Space	7.58E+11	6.84E+11	7.58E+11	7.33E+11	7.58E+11	7.33E+11	7.58E+11	7.58E+11	7.33E+11	7.58E+11	7.33E+11	7.58E+11	8.92E+12
PastureHay	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland	3.51E+10	3.17E+10	3.51E+10	3.40E+10	3.51E+10	3.40E+10	3.51E+10	3.51E+10	3.40E+10	3.51E+10	3.40E+10	3.51E+10	4.13E+11

Table C.18 Monthly, directly deposited fecal coliform loads in Goode Creek (reach 19).

Source Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human	2.75E+11	2.48E+11	2.75E+11	2.66E+11	2.75E+11	2.66E+11	2.75E+11	2.75E+11	2.66E+11	2.75E+11	2.66E+11	2.75E+11	3.23E+12
Livestock	0	0	0	0	0	0	0	0	0	0	0	0	0
Wildlife	4.48E+10	4.05E+10	4.48E+10	4.34E+10	4.48E+10	4.34E+10	4.48E+10	4.48E+10	4.34E+10	4.48E+10	4.34E+10	4.48E+10	5.28E+11

Table C.19 Existing annual loads from land-based sources for Goode Creek (subwatershed 19).

Source	Barren	Commercial	Cropland	Forest	LAX	LMIR	OpenSpace	PastureHay	Wetland
Beef	0	0	0	0	0	0	0	0	0
Beef Calf	0	0	0	0	0	0	0	0	0
Cats	0	0	0	0	0	2.96E+08	0	0	0
Dairy	0	0	0	0	0	0	0	0	0
Dairy Calf	0	0	0	0	0	0	0	0	0
Dairy Dry	0	0	0	0	0	0	0	0	0
Deer	0	0	0	2.10E+12	0	1.30E+12	9.72E+11	0	4.99E+10
Dogs	0	0	0	0	0	3.27E+14	0	0	0
Duck	6.69E+06	7.52E+07	0	4.59E+08	0	6.01E+08	3.70E+08	0	2.81E+07
Goose	4.32E+08	4.86E+09	0	2.96E+10	0	3.88E+10	2.39E+10	0	1.81E+09
Hogs	0	0	0	0	0	0	0	0	0
Horse	0	0	0	0	0	0	0	0	0
Muskrat	4.41E+10	4.96E+11	0	3.03E+12	0	3.96E+12	2.44E+12	0	1.85E+11
People w/Septic Failures	0	0	0	0	0	8.07E+11	0	0	0
Raccoon	6.24E+10	1.13E+12	0	3.53E+12	0	7.27E+12	5.49E+12	0	1.76E+11
Sheep	0	0	0	0	0	0	0	0	0
Turkey	0	0	0	9.37E+08	0	0	0	0	2.23E+07

Table C.20 Existing annual loads from direct-deposition sources for Goode Creek (reach 19).

Source	Annual Total Loads (cfu/yr)
Beaver	5.84E+03
Beef	0
Beef Calf	0
Dairy	0
Dairy Calf	0
Dairy Dry	0
Deer	2.21E+09
Duck	6.00E+07
Goose	2.55E+09
Hogs	0
Horse	0
Muskrat	4.79E+11
People w/Straight Pipes	3.23E+12
Raccoon	4.42E+10
Sheep	0
Turkey	4.80E+05

James River (upper)

Table C.21 Current conditions of land applied fecal coliform load for James River (upper) by land use (subwatersheds 1-4, 16, 24-28).

Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	6.44E+11	5.82E+11	6.44E+11	6.23E+11	6.44E+11	6.23E+11	6.44E+11	6.44E+11	6.23E+11	6.44E+11	6.23E+11	6.44E+11	7.58E+12
Commercial	1.28E+11	1.16E+11	1.28E+11	1.24E+11	1.28E+11	1.24E+11	1.28E+11	1.28E+11	1.24E+11	1.28E+11	1.24E+11	1.28E+11	1.51E+12
Cropland	2.53E+13	2.48E+13	2.12E+14	2.12E+14	5.64E+13	4.35E+12	4.50E+12	4.50E+12	2.22E+14	2.12E+14	2.51E+13	2.53E+13	1.03E+15
Forest	7.95E+13	7.18E+13	7.95E+13	7.70E+13	7.95E+13	7.70E+13	7.95E+13	7.95E+13	7.70E+13	7.95E+13	7.70E+13	7.95E+13	9.36E+14
LAX	6.11E+12	5.52E+12	8.55E+12	1.13E+13	1.16E+13	1.36E+13	1.41E+13	1.41E+13	1.13E+13	8.55E+12	8.28E+12	6.11E+12	1.19E+14
LMIR	1.94E+14	1.75E+14	1.92E+14	3.24E+14	1.90E+14	1.83E+14	1.88E+14	1.88E+14	1.82E+14	1.87E+14	1.82E+14	1.91E+14	2.38E+15
Open Space	2.27E+12	2.05E+12	2.27E+12	2.19E+12	2.27E+12	2.19E+12	2.27E+12	2.27E+12	2.19E+12	2.27E+12	2.19E+12	2.27E+12	2.67E+13
PastureHay	3.24E+14	2.92E+14	3.20E+14	3.06E+14	3.16E+14	3.23E+14	3.33E+14	3.33E+14	3.06E+14	3.20E+14	3.10E+14	3.24E+14	3.81E+15
Wetland	1.71E+13	1.54E+13	1.71E+13	1.65E+13	1.71E+13	1.65E+13	1.71E+13	1.71E+13	1.65E+13	1.71E+13	1.65E+13	1.71E+13	2.01E+14

Table C.22 Monthly, directly deposited fecal coliform loads in James River (upper) (reaches 1-4, 16, 24-28).

Source Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human	1.79E+13	1.62E+13	1.79E+13	1.74E+13	1.79E+13	1.74E+13	1.79E+13	1.79E+13	1.74E+13	1.79E+13	1.74E+13	1.79E+13	2.11E+14
Livestock	1.91E+12	1.73E+12	2.96E+12	4.14E+12	4.27E+12	5.14E+12	5.32E+12	5.32E+12	4.14E+12	2.96E+12	2.86E+12	1.91E+12	4.26E+13
Wildlife	2.18E+12	1.97E+12	2.18E+12	2.11E+12	2.18E+12	2.11E+12	2.18E+12	2.18E+12	2.11E+12	2.18E+12	2.11E+12	2.18E+12	2.56E+13

Table C.23 Existing annual loads from land-based sources for James River (upper) (subwatersheds 1-4, 16, 24-28).

Source	Barren	Commercial	Cropland	Forest	LAX	LMIR	OpenSpace	PastureHay	Wetland
Beef	0	0	0	0	5.15E+13	0	0	1.40E+15	0
Beef Calf	0	0	0	0	1.99E+13	0	0	5.39E+14	0
Cats	0	0	0	0	0	1.81E+09	0	0	0
Dairy	0	0	8.72E+14	0	0	0	0	5.57E+13	0
Dairy Calf	0	0	1.04E+14	0	0	0	0	6.64E+12	0
Dairy Dry	0	0	0	0	2.81E+13	0	0	4.94E+14	0
Deer	0	0	1.25E+13	2.08E+14	1.66E+12	6.35E+12	2.31E+12	6.31E+13	1.26E+13
Dogs	0	0	0	0	0	2.00E+15	0	0	0
Duck	3.84E+08	2.36E+07	1.82E+09	3.80E+10	2.01E+09	1.77E+09	1.04E+09	7.21E+09	2.12E+10
Goose	2.42E+10	1.49E+09	1.15E+11	2.40E+12	1.27E+11	1.12E+11	6.58E+10	4.55E+11	1.33E+12
Hogs	0	0	0	0	0	0	0	3.07E+13	0
Horse	0	0	0	0	0	0	0	1.04E+15	0
Muskrat	2.53E+12	1.56E+11	1.20E+13	2.51E+14	1.33E+13	1.17E+13	6.88E+12	4.75E+13	1.40E+14
People w/Septic Failures	0	0	0	0	0	3.13E+14	0	0	0
Raccoon	5.03E+12	1.35E+12	2.83E+13	4.75E+14	4.42E+12	4.47E+13	1.74E+13	1.36E+14	4.76E+13
Sheep	0	0	0	0	0	0	0	1.81E+12	0
Turkey	0	0	1.48E+09	9.86E+10	1.97E+08	0	0	7.48E+09	6.00E+09

Table C.24 Existing annual loads from direct-deposition sources for James River (upper) (reaches 1-4, 16, 24-28).

Source	Annual Total Loads (cfu/yr)
Beaver	2.31E+05
Beef	2.21E+13
Beef Calf	8.53E+12
Dairy	0
Dairy Calf	0
Dairy Dry	1.21E+13
Deer	1.53E+11
Duck	2.94E+09
Goose	1.22E+11
Hogs	0
Horse	0
Muskrat	2.34E+13
People w/Straight Pipes	2.11E+14
Raccoon	1.91E+12
Sheep	0
Turkey	5.69E+07

James River (lower)

Table C.25 Current conditions of land applied fecal coliform load for James River (lower) by land use (subwatersheds 1-9, 24-28, 16, 17, 41, 46-51, 57- 60,76).

Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	7.52E+11	6.79E+11	7.52E+11	7.27E+11	7.52E+11	7.27E+11	7.52E+11	7.52E+11	7.27E+11	7.52E+11	7.27E+11	7.52E+11	8.85E+12
Commercial	7.87E+11	7.11E+11	7.87E+11	7.62E+11	7.87E+11	7.62E+11	7.87E+11	7.87E+11	7.62E+11	7.87E+11	7.62E+11	7.87E+11	9.27E+12
Cropland	2.53E+13	2.48E+13	2.12E+14	2.12E+14	5.64E+13	4.37E+12	4.52E+12	4.52E+12	2.22E+14	2.12E+14	2.51E+13	2.53E+13	1.03E+15
Forest	8.75E+13	7.90E+13	8.75E+13	8.46E+13	8.75E+13	8.46E+13	8.75E+13	8.75E+13	8.46E+13	8.75E+13	8.46E+13	8.75E+13	1.03E+15
LAX	6.16E+12	5.56E+12	8.61E+12	1.13E+13	1.17E+13	1.37E+13	1.41E+13	1.41E+13	1.13E+13	8.61E+12	8.33E+12	6.16E+12	1.20E+14
LMIR	4.33E+14	3.90E+14	4.30E+14	5.74E+14	4.28E+14	4.14E+14	4.26E+14	4.26E+14	4.12E+14	4.25E+14	4.12E+14	4.29E+14	5.20E+15
Open Space	6.89E+12	6.22E+12	6.89E+12	6.67E+12	6.89E+12	6.67E+12	6.89E+12	6.89E+12	6.67E+12	6.89E+12	6.67E+12	6.89E+12	8.11E+13
PastureHay	3.28E+14	2.96E+14	3.24E+14	3.09E+14	3.20E+14	3.27E+14	3.37E+14	3.37E+14	3.09E+14	3.24E+14	3.14E+14	3.28E+14	3.85E+15
Wetland	1.94E+13	1.75E+13	1.94E+13	1.88E+13	1.94E+13	1.88E+13	1.94E+13	1.94E+13	1.88E+13	1.94E+13	1.88E+13	1.94E+13	2.29E+14

Table C.26 Monthly, directly deposited fecal coliform loads in James River (lower) (reaches 1-9, 24-28, 16, 17, 41, 46-51, 57-60,76).

Source Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human	2.00E+13	1.80E+13	2.00E+13	1.93E+13	2.00E+13	1.93E+13	2.00E+13	2.00E+13	1.93E+13	2.00E+13	1.93E+13	2.00E+13	2.35E+14
Livestock	1.92E+12	1.74E+12	2.97E+12	4.17E+12	4.30E+12	5.17E+12	5.35E+12	5.35E+12	4.17E+12	2.97E+12	2.88E+12	1.92E+12	4.29E+13
Wildlife	2.55E+12	2.30E+12	2.55E+12	2.47E+12	2.55E+12	2.47E+12	2.55E+12	2.55E+12	2.47E+12	2.55E+12	2.47E+12	2.55E+12	3.00E+13

Table C.27 Existing annual loads from land-based sources for James River (lower) (subwatersheds 1-9, 24-28, 16, 17, 41, 46-51, 57- 60,76).

Source	Barren	Commercial	Cropland	Forest	LAX	LMIR	OpenSpace	PastureHay	Wetland
Beef	0	0	0	0	5.19E+13	0	0	1.41E+15	0
Beef Calf	0	0	0	0	2.00E+13	0	0	5.42E+14	0
BisonZoo	0	0	0	0	0	0	0	2.56E+12	0
Cats	0	0	0	0	0	4.28E+09	0	0	0
Dairy	0	0	8.72E+14	0	0	0	0	5.57E+13	0
Dairy Calf	0	0	1.04E+14	0	0	0	0	6.64E+12	0
Dairy Dry	0	0	0	0	2.81E+13	0	0	4.94E+14	0
Deer	0	0	1.26E+13	2.25E+14	1.69E+12	1.16E+13	7.51E+12	6.38E+13	1.42E+13
DeerZoo	0	0	0	0	0	0	0	3.11E+12	0
Dogs	0	0	0	0	0	4.73E+15	0	0	0
Duck	4.34E+08	3.39E+08	1.82E+09	4.27E+10	2.04E+09	4.01E+09	3.04E+09	7.31E+09	2.43E+10
Goose	2.74E+10	2.14E+10	1.15E+11	2.69E+12	1.29E+11	2.53E+11	1.91E+11	4.61E+11	1.53E+12
Hogs	0	0	0	0	0	0	0	3.37E+13	0
Horse	0	0	0	0	0	0	0	1.05E+15	0
Muskrat	2.86E+12	2.24E+12	1.20E+13	2.81E+14	1.35E+13	2.65E+13	2.00E+13	4.82E+13	1.60E+14
People w/Septic Failures	0	0	0	0	0	3.58E+14	0	0	0
Raccoon	5.96E+12	7.01E+12	2.85E+13	5.20E+14	4.48E+12	7.60E+13	5.34E+13	1.37E+14	5.27E+13
Sheep	0	0	0	0	0	0	0	1.85E+12	0
Turkey	0	0	1.49E+09	1.07E+11	2.01E+08	0	0	7.57E+09	6.76E+09

Table C.28 Existing annual loads from direct-deposition sources for James River (lower) (reaches 1-9, 24-28, 16, 17, 41, 46-51, 57- 60,76).

Source	Annual Total Loads (cfu/yr)
Beaver	2.75E+05
Beef	2.23E+13
Beef Calf	8.58E+12
Dairy	0
Dairy Calf	0
Dairy Dry	1.21E+13
Deer	1.69E+11
Duck	3.45E+09
Goose	1.43E+11
Hogs	0
Horse	0
Muskrat	2.75E+13
People w/Straight Pipes	2.35E+14
Raccoon	2.22E+12
Sheep	0
Turkey	6.15E+07

James River (tidal)

Table C.29 Current conditions of land applied fecal coliform load for James River (tidal) by land use (all subwatersheds 1-79).

Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	1.99E+12	1.80E+12	1.99E+12	1.93E+12	1.99E+12	1.93E+12	1.99E+12	1.99E+12	1.93E+12	1.99E+12	1.93E+12	1.99E+12	2.35E+13
Commercial	1.81E+12	1.63E+12	1.81E+12	1.75E+12	1.81E+12	1.75E+12	1.81E+12	1.81E+12	1.75E+12	1.81E+12	1.75E+12	1.81E+12	2.13E+13
Cropland	3.46E+13	3.32E+13	2.23E+14	2.23E+14	6.60E+13	1.32E+13	1.36E+13	1.36E+13	2.33E+14	2.23E+14	3.41E+13	3.46E+13	1.15E+15
Forest	1.72E+14	1.55E+14	1.72E+14	1.66E+14	1.72E+14	1.66E+14	1.72E+14	1.72E+14	1.66E+14	1.72E+14	1.66E+14	1.72E+14	2.02E+15
LAX	8.44E+12	7.62E+12	1.16E+13	1.50E+13	1.55E+13	1.80E+13	1.86E+13	1.86E+13	1.50E+13	1.16E+13	1.12E+13	8.44E+12	1.60E+14
LMIR	8.19E+14	7.38E+14	8.13E+14	9.44E+14	8.10E+14	7.83E+14	8.05E+14	8.05E+14	7.79E+14	8.04E+14	7.79E+14	8.11E+14	9.69E+15
Open Space	2.59E+13	2.34E+13	2.59E+13	2.51E+13	2.59E+13	2.51E+13	2.59E+13	2.59E+13	2.51E+13	2.59E+13	2.51E+13	2.59E+13	3.05E+14
PastureHay	4.93E+14	4.45E+14	4.88E+14	4.67E+14	4.83E+14	4.84E+14	4.99E+14	4.99E+14	4.67E+14	4.88E+14	4.73E+14	4.93E+14	5.77E+15
Wetland	5.07E+13	4.57E+13	5.07E+13	4.91E+13	5.07E+13	4.91E+13	5.07E+13	5.07E+13	4.91E+13	5.07E+13	4.91E+13	5.07E+13	5.97E+14

Table C.30 Monthly, directly deposited fecal coliform loads in James River (tidal) (all reaches 1-79).

Source Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human	4.09E+13	3.69E+13	4.09E+13	3.96E+13	4.09E+13	3.96E+13	4.09E+13	4.09E+13	3.96E+13	4.09E+13	3.96E+13	4.09E+13	4.82E+14
Livestock	2.59E+12	2.34E+12	3.92E+12	5.45E+12	5.63E+12	6.73E+12	6.97E+12	6.97E+12	5.45E+12	3.92E+12	3.80E+12	2.59E+12	5.63E+13
Wildlife	5.94E+12	5.37E+12	5.94E+12	5.75E+12	5.94E+12	5.75E+12	5.94E+12	5.94E+12	5.75E+12	5.94E+12	5.75E+12	5.94E+12	7.00E+13

Table C.31 Existing annual loads from land-based sources for James River (tidal) (all subwatersheds 1-79).

Source	Barren	Commercial	Cropland	Forest	LAX	LMIR	OpenSpace	PastureHay	Wetland
Beef	0	0	0	0	7.53E+13	0	0	2.05E+15	0
Beef Calf	0	0	0	0	2.78E+13	0	0	7.55E+14	0
BisonZoo	0	0	0	0	0	0	0	2.56E+12	0
Cats	0	0	0	0	0	8.05E+09	0	0	0
Dairy	0	0	8.82E+14	0	0	0	0	5.63E+13	0
Dairy Calf	0	0	1.04E+14	0	0	0	0	6.64E+12	0
Dairy Dry	0	0	0	0	2.81E+13	0	0	4.94E+14	0
Deer	0	0	4.10E+13	4.29E+14	2.23E+12	2.64E+13	2.99E+13	1.32E+14	4.39E+13
DeerZoo	0	0	0	0	0	0	0	3.11E+12	0
Dogs	0	0	0	0	0	8.90E+15	0	0	0
Duck	1.28E+09	8.37E+08	4.76E+09	9.44E+10	3.09E+09	1.07E+10	1.23E+10	1.27E+10	6.38E+10
Goose	8.18E+10	5.35E+10	3.05E+11	6.03E+12	1.97E+11	6.87E+11	7.90E+11	8.09E+11	4.08E+12
Hogs	0	0	0	0	0	0	0	1.09E+14	0
Horse	0	0	0	0	0	0	0	1.82E+15	0
Muskrat	8.42E+12	5.53E+12	3.14E+13	6.22E+14	2.05E+13	7.08E+13	8.12E+13	8.38E+13	4.20E+14
People w/Septic Failures	0	0	0	0	0	5.28E+14	0	0	0
Raccoon	1.50E+13	1.57E+13	8.77E+13	9.64E+14	5.58E+12	1.71E+14	1.93E+14	2.61E+14	1.28E+14
Sheep	0	0	0	0	0	0	0	4.33E+12	0
Turkey	0	0	4.66E+09	1.98E+11	2.62E+08	0	0	1.52E+10	2.01E+10

Table C.32 Existing annual loads from direct-deposition sources for James River (tidal) (all reaches 1-79).

Source	Annual Total Loads (cfu/yr)
Beaver	6.05E+05
Beef	3.24E+13
Beef Calf	1.20E+13
Dairy	0
Dairy Calf	0
Dairy Dry	1.21E+13
Deer	3.53E+11
Duck	8.11E+09
Goose	3.41E+11
Hogs	0
Horse	0
Muskrat	6.47E+13
People w/Straight Pipes	4.82E+14
Raccoon	4.62E+12
Sheep	0
Turkey	1.19E+08

No Name Creek

Table C.33 Current conditions of land applied fecal coliform load for No Name Creek by land use (subwatershed 23).

Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	2.35E+09	2.12E+09	2.35E+09	2.27E+09	2.35E+09	2.27E+09	2.35E+09	2.35E+09	2.27E+09	2.35E+09	2.27E+09	2.35E+09	2.76E+10
Commercial	2.43E+10	2.20E+10	2.43E+10	2.36E+10	2.43E+10	2.36E+10	2.43E+10	2.43E+10	2.36E+10	2.43E+10	2.36E+10	2.43E+10	2.87E+11
Cropland	4.21E+10	3.80E+10	4.21E+10	4.07E+10	4.21E+10	4.07E+10	4.21E+10	4.21E+10	4.07E+10	4.21E+10	4.07E+10	4.21E+10	4.96E+11
Forest	3.85E+11	3.47E+11	3.85E+11	3.72E+11	3.85E+11	3.72E+11	3.85E+11	3.85E+11	3.72E+11	3.85E+11	3.72E+11	3.85E+11	4.53E+12
LAX	0	0	0	0	0	0	0	0	0	0	0	0	0
LMIR	3.44E+12	3.10E+12	3.43E+12	3.31E+12	3.41E+12	3.30E+12	3.40E+12	3.40E+12	3.29E+12	3.39E+12	3.29E+12	3.42E+12	4.02E+13
Open Space	1.84E+11	1.66E+11	1.84E+11	1.78E+11	1.84E+11	1.78E+11	1.84E+11	1.84E+11	1.78E+11	1.84E+11	1.78E+11	1.84E+11	2.16E+12
PastureHay	2.94E+10	2.66E+10	2.94E+10	2.85E+10	2.94E+10	2.85E+10	2.94E+10	2.94E+10	2.85E+10	2.94E+10	2.85E+10	2.94E+10	3.46E+11
Wetland	5.37E+10	4.85E+10	5.37E+10	5.19E+10	5.37E+10	5.19E+10	5.37E+10	5.37E+10	5.19E+10	5.37E+10	5.19E+10	5.37E+10	6.32E+11

Table C.34 Monthly, directly deposited fecal coliform loads in No Name Creek (reach 23).

Source Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human	2.75E+11	2.48E+11	2.75E+11	2.66E+11	2.75E+11	2.66E+11	2.75E+11	2.75E+11	2.66E+11	2.75E+11	2.66E+11	2.75E+11	3.23E+12
Livestock	0	0	0	0	0	0	0	0	0	0	0	0	0
Wildlife	1.03E+10	9.31E+09	1.03E+10	9.97E+09	1.03E+10	9.97E+09	1.03E+10	1.03E+10	9.97E+09	1.03E+10	9.97E+09	1.03E+10	1.21E+11

Table C.35 Existing annual loads from land-based sources for No Name Creek (subwatershed 23).

Source	Barren	Commercial	Cropland	Forest	LAX	LMIR	OpenSpace	PastureHay	Wetland
Beef	0	0	0	0	0	0	0	0	0
Beef Calf	0	0	0	0	0	0	0	0	0
Cats	0	0	0	0	0	3.31E+07	0	0	0
Dairy	0	0	0	0	0	0	0	0	0
Dairy Calf	0	0	0	0	0	0	0	0	0
Dairy Dry	0	0	0	0	0	0	0	0	0
Deer	0	0	1.31E+11	1.02E+12	0	2.36E+11	2.31E+11	1.09E+11	9.83E+10
Dogs	0	0	0	0	0	3.66E+13	0	0	0
Duck	0	1.34E+06	1.61E+07	1.50E+08	0	7.49E+07	5.81E+07	2.68E+06	2.81E+07
Goose	0	8.63E+07	1.04E+09	9.68E+09	0	4.83E+09	3.75E+09	1.73E+08	1.81E+09
Hogs	0	0	0	0	0	0	0	0	0
Horse	0	0	0	0	0	0	0	0	0
Muskrat	0	8.82E+09	1.06E+11	9.89E+11	0	4.94E+11	3.83E+11	1.76E+10	1.85E+11
People w/Septic Failures	0	0	0	0	0	1.26E+12	0	0	0
Raccoon	2.76E+10	2.78E+11	2.58E+11	2.51E+12	0	1.61E+12	1.55E+12	2.19E+11	3.47E+11
Sheep	0	0	0	0	0	0	0	0	0
Turkey	0	0	1.46E+07	4.56E+08	0	0	0	1.22E+07	4.39E+07

Table C.36 Existing annual loads from direct-deposition sources for No Name Creek (reach 23).

Source	Annual Total Loads (cfu/yr)
Beaver	1.09E+03
Beef	0
Beef Calf	0
Dairy	0
Dairy Calf	0
Dairy Dry	0
Deer	9.14E+08
Duck	1.29E+07
Goose	5.48E+08
Hogs	0
Horse	0
Muskrat	1.03E+11
People w/Straight Pipes	3.23E+12
Raccoon	1.70E+10
Sheep	0
Turkey	2.64E+05

Powhite Creek

Table C.37 Current conditions of land applied fecal coliform load for Powhite Creek by land use (subwatershed 17).

Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	3.20E+10	2.89E+10	3.20E+10	3.10E+10	3.20E+10	3.10E+10	3.20E+10	3.20E+10	3.10E+10	3.20E+10	3.10E+10	3.20E+10	3.77E+11
Commercial	2.67E+10	2.42E+10	2.67E+10	2.59E+10	2.67E+10	2.59E+10	2.67E+10	2.67E+10	2.59E+10	2.67E+10	2.59E+10	2.67E+10	3.15E+11
Cropland	2.34E+10	2.11E+10	2.34E+10	2.26E+10	2.34E+10	2.26E+10	2.34E+10	2.34E+10	2.26E+10	2.34E+10	2.26E+10	2.34E+10	2.75E+11
Forest	3.20E+12	2.89E+12	3.20E+12	3.09E+12	3.20E+12	3.09E+12	3.20E+12	3.20E+12	3.09E+12	3.20E+12	3.09E+12	3.20E+12	3.76E+13
LAX	2.35E+10	2.13E+10	3.30E+10	4.41E+10	4.55E+10	5.32E+10	5.50E+10	5.50E+10	4.41E+10	3.30E+10	3.19E+10	2.35E+10	4.63E+11
LMIR	4.15E+13	3.75E+13	4.14E+13	4.71E+13	4.13E+13	4.00E+13	4.12E+13	4.12E+13	3.99E+13	4.12E+13	3.99E+13	4.14E+13	4.94E+14
Open Space	2.02E+12	1.83E+12	2.02E+12	1.96E+12	2.02E+12	1.96E+12	2.02E+12	2.02E+12	1.96E+12	2.02E+12	1.96E+12	2.02E+12	2.38E+13
PastureHay	2.69E+12	2.43E+12	2.68E+12	2.57E+12	2.66E+12	2.56E+12	2.65E+12	2.65E+12	2.57E+12	2.68E+12	2.59E+12	2.69E+12	3.14E+13
Wetland	7.57E+11	6.84E+11	7.57E+11	7.33E+11	7.57E+11	7.33E+11	7.57E+11	7.57E+11	7.33E+11	7.57E+11	7.33E+11	7.57E+11	8.91E+12

Table C.38 Monthly, directly deposited fecal coliform loads in Powhite Creek (reach 17).

Source Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human	8.24E+11	7.44E+11	8.24E+11	7.97E+11	8.24E+11	7.97E+11	8.24E+11	8.24E+11	7.97E+11	8.24E+11	7.97E+11	8.24E+11	9.70E+12
Livestock	9.43E+09	8.52E+09	1.35E+10	1.83E+10	1.89E+10	2.22E+10	2.29E+10	2.29E+10	1.83E+10	1.35E+10	1.30E+10	9.43E+09	1.91E+11
Wildlife	1.14E+11	1.03E+11	1.14E+11	1.10E+11	1.14E+11	1.10E+11	1.14E+11	1.14E+11	1.10E+11	1.14E+11	1.10E+11	1.14E+11	1.34E+12

Table C.39 Existing annual loads from land-based sources for Powhite Creek (subwatershed 17).

Source	Barren	Commercial	Cropland	Forest	LAX	LMIR	OpenSpace	PastureHay	Wetland
Beef	0	0	0	0	3.59E+11	0	0	9.72E+12	0
Beef Calf	0	0	0	0	8.62E+10	0	0	2.33E+12	0
Cats	0	0	0	0	0	4.21E+08	0	0	0
Dairy	0	0	0	0	0	0	0	0	0
Dairy Calf	0	0	0	0	0	0	0	0	0
Dairy Dry	0	0	0	0	0	0	0	0	0
Deer	0	0	8.19E+10	7.92E+12	2.81E+09	9.39E+11	2.20E+12	3.78E+11	6.29E+11
Dogs	0	0	0	0	0	4.65E+14	0	0	0
Duck	8.34E+06	1.15E+07	0	1.47E+09	1.00E+06	6.55E+08	8.40E+08	1.01E+07	8.43E+08
Goose	5.26E+08	7.26E+08	0	9.28E+10	6.33E+07	4.13E+10	5.30E+10	6.39E+08	5.32E+10
Hogs	0	0	0	0	0	0	0	2.25E+12	0
Horse	0	0	0	0	0	0	0	1.59E+13	0
Muskrat	5.50E+10	7.59E+10	0	9.71E+12	6.62E+09	4.32E+12	5.54E+12	6.68E+10	5.56E+12
People w/Septic Failures	0	0	0	0	0	1.59E+13	0	0	0
Raccoon	3.22E+11	2.38E+11	1.93E+11	1.99E+13	8.45E+09	7.11E+12	1.60E+13	7.87E+11	2.67E+12
Sheep	0	0	0	0	0	0	0	1.71E+10	0
Turkey	0	0	9.71E+06	3.76E+09	3.33E+05	0	0	4.48E+07	2.99E+08

Table C.40 Existing annual loads from direct-deposition sources for Powhite Creek (reach 17).

Source	Annual Total Loads (cfu/yr)
Beaver	1.31E+04
Beef	1.54E+11
Beef Calf	3.69E+10
Dairy	0
Dairy Calf	0
Dairy Dry	0
Deer	6.08E+09
Duck	1.52E+08
Goose	6.30E+09
Hogs	0
Horse	0
Muskrat	1.21E+12
People w/Straight Pipes	9.70E+12
Raccoon	1.19E+11
Sheep	0
Turkey	2.06E+06

Reedy Creek

Table C.41 Current conditions of land applied fecal coliform load for Reedy Creek by land use (subwatersheds 41, 57).

Land use	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Barren	6.32E+09	5.71E+09	6.32E+09	6.12E+09	6.32E+09	6.12E+09	6.32E+09	6.32E+09	6.12E+09	6.32E+09	6.12E+09	6.32E+09	7.44E+10
Commercial	8.63E+10	7.80E+10	8.63E+10	8.36E+10	8.63E+10	8.36E+10	8.63E+10	8.63E+10	8.36E+10	8.63E+10	8.36E+10	8.63E+10	1.02E+12
Cropland	0	0	0	0	0	0	0	0	0	0	0	0	0
Forest	8.72E+11	7.88E+11	8.72E+11	8.44E+11	8.72E+11	8.44E+11	8.72E+11	8.72E+11	8.44E+11	8.72E+11	8.44E+11	8.72E+11	1.03E+13
LAX	0	0	0	0	0	0	0	0	0	0	0	0	0
LMIR	3.40E+13	3.07E+13	3.40E+13	3.36E+13	3.40E+13	3.29E+13	3.40E+13	3.40E+13	3.29E+13	3.40E+13	3.29E+13	3.40E+13	4.01E+14
Open Space	6.07E+11	5.48E+11	6.07E+11	5.88E+11	6.07E+11	5.88E+11	6.07E+11	6.07E+11	5.88E+11	6.07E+11	5.88E+11	6.07E+11	7.15E+12
PastureHay	0	0	0	0	0	0	0	0	0	0	0	0	0
Wetland	3.69E+10	3.33E+10	3.69E+10	3.57E+10	3.69E+10	3.57E+10	3.69E+10	3.69E+10	3.57E+10	3.69E+10	3.57E+10	3.69E+10	4.34E+11

Table C.42 Monthly, directly deposited fecal coliform loads in Reedy Creek (reaches 41, 57).

Source Type	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Loads (cfu/yr)
Human	9.16E+11	8.27E+11	9.16E+11	8.86E+11	9.16E+11	8.86E+11	9.16E+11	9.16E+11	8.86E+11	9.16E+11	8.86E+11	9.16E+11	1.08E+13
Livestock	0	0	0	0	0	0	0	0	0	0	0	0	0
Wildlife	2.71E+10	2.45E+10	2.71E+10	2.62E+10	2.71E+10	2.62E+10	2.71E+10	2.71E+10	2.62E+10	2.71E+10	2.62E+10	2.71E+10	3.19E+11

Table C.43 Existing annual loads from land-based sources for Reedy Creek (subwatersheds 41, 57).

Source	Barren	Commercial	Cropland	Forest	LAX	LMIR	OpenSpace	PastureHay	Wetland
Beef	0	0	0	0	0	0	0	0	0
Beef Calf	0	0	0	0	0	0	0	0	0
Cats	0	0	0	0	0	3.55E+08	0	0	0
Dairy	0	0	0	0	0	0	0	0	0
Dairy Calf	0	0	0	0	0	0	0	0	0
Dairy Dry	0	0	0	0	0	0	0	0	0
Deer	0	0	0	2.14E+12	0	7.35E+11	7.09E+11	0	6.97E+10
Dogs	0	0	0	0	0	3.92E+14	0	0	0
Duck	0	3.13E+07	0	4.46E+08	0	2.15E+08	1.82E+08	0	8.89E+06
Goose	0	1.97E+09	0	2.81E+10	0	1.35E+10	1.15E+10	0	5.60E+08
Hogs	0	0	0	0	0	0	0	0	0
Horse	0	0	0	0	0	0	0	0	0
Muskrat	0	2.06E+11	0	2.94E+12	0	1.42E+12	1.20E+12	0	5.86E+10
People w/Septic Failures	0	0	0	0	0	1.61E+12	0	0	0
Raccoon	7.44E+10	8.08E+11	0	5.15E+12	0	4.92E+12	5.23E+12	0	3.06E+11
Sheep	0	0	0	0	0	0	0	0	0
Turkey	0	0	0	1.02E+09	0	0	0	0	3.31E+07

Table C.44 Existing annual loads from direct-deposition sources for Reedy Creek (reaches 41, 57).

Source	Annual Total Loads (cfu/yr)
Beaver	2.19E+03
Beef	0
Beef Calf	0
Dairy	0
Dairy Calf	0
Dairy Dry	0
Deer	1.83E+09
Duck	3.44E+07
Goose	1.43E+09
Hogs	0
Horse	0
Muskrat	2.74E+11
People w/Straight Pipes	1.08E+13
Raccoon	4.13E+10
Sheep	0
Turkey	5.26E+05

APPENDIX D: HSPF SENSITIVITY ANALYSES

Sensitivity Analyses

Sensitivity analyses are performed to determine a model's response to changes in certain parameters. This process involves changing a single parameter a certain percentage from a baseline value while holding all other parameters constant. This process is repeated for several parameters in order to gain a complete picture of the model's behavior. The information gained during a sensitivity analysis can aid in model calibration, and it can also help to determine the potential effects of uncertainty in parameter estimation. Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.*, seasonal and spatial variability of waste production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads).

HSPF - Hydrology Sensitivity Analysis

A hydrology sensitivity analysis was preformed during the development of the Total Maximum Daily Load Development for the James River and Tributaries – Lower Piedmont Region (VADEQ, 2007a) project and applies to this project also. The HSPF parameters adjusted for the hydrologic sensitivity analysis are presented in Table D.1, with base values for the model runs given. The model was run for water years 2000-2003 and the parameters were adjusted to -50%, -10%, 10%, and 50% of the base value, except for AWRC. AGWRC was set at 0.98 initial and then changed to the values in Table D.2, to show the hydrology changes when this parameter is at its minimum (0.85) and its maximum (0.999). Where an increase of 50% exceeded the maximum value for the parameters, the maximum value was used and the parameters increased over the base value were reported.

The hydrologic quantities of greatest interest in a fecal coliform model are those that govern peak flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of fecal coliform from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration such as INFILT (Infiltration), LZSN (Lower Zone Storage), and by UZSN

(Upper Zone Storage), which governs surface transport, and LZETP (Lower Zone Evapotranspiration), which affects soil moisture. Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows were AGWRC (Groundwater Recession Rate), BASETP (Base Flow Evapotranspiration), LZETP, INFILT, DEEPFR (Groundwater Inflow to Deep Recharge), UZSN, CEPSC (Interception Storage Capacity), and LZSN. The responses of these and other hydrologic outputs are reported in Table D.2.

Table D.1 HSPF base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
LZSN	Lower Zone Nominal Storage	in	3.421-5.966
INFILT	Soil Infiltration Capacity	in/hr	0.0316-1013
BASETP	Base Flow Evapotranspiration	---	0.1-0.1
INTFW	Interflow Inflow	---	2.0-2.0
DEEPFR	Groundwater Inflow to Deep Recharge	---	0.1-0.1
AGWRC	Groundwater Recession rate	---	0.98
KVARY	Groundwater Recession Flow	1/in	1.0
MON-INTERCEP	Monthly Interception Storage Capacity	in	0.01-0.3
MON-UZSN	Monthly Upper Zone Nominal Storage	in	0.18-0.98
MON-LZETP	Monthly Lower Zone Evapotranspiration	in	0.1-0.8

Table D.2 HSPF Sensitivity analysis results for hydrologic model parameters for the James River.

Model Parameter	Parameter Change (%)	Percent Change In: Total Flow	High Flows	Low Flows	Winter Flow Volume	Spring Flow Volume	Summer Flow Volume	Fall Flow Volume	Total Storm Volume
AGWRC	0.85	0.42	0.72	-1.32	0.46	0.04	0.10	1.76	0.46
AGWRC	0.92	0.27	0.42	-1.12	0.47	0.03	-0.25	1.17	0.30
AGWRC	0.96	0.12	0.16	-0.79	0.37	0.03	-0.29	0.39	0.13
AGWRC	0.999	-2.81	-1.14	-4.13	-3.43	-2.31	-2.06	-3.95	-3.11
BASETP	-50	0.36	-0.02	2.13	-0.07	0.51	0.90	0.12	-0.10
BASETP	-10	0.06	0.00	0.33	-0.01	0.10	0.12	0.03	0.06
BASETP	10	-0.06	0.00	-0.29	0.01	-0.09	-0.10	-0.03	-0.06
BASETP	50	-0.24	0.02	-1.19	0.04	-0.39	-0.40	-0.14	-0.24
DEEPFR	-50	0.31	0.11	0.68	0.32	0.25	0.30	0.45	0.34
DEEPFR	-10	0.06	0.02	0.14	0.06	0.05	0.06	0.09	0.07
DEEPFR	10	-0.06	-0.02	-0.13	-0.06	-0.05	-0.06	-0.09	-0.07
DEEPFR	50	-0.31	-0.11	-0.67	-0.32	-0.25	-0.30	-0.45	-0.34
INFILT	-50	0.24	0.53	-1.27	0.31	-0.12	0.59	0.61	0.27
INFILT	-10	0.04	0.09	-0.26	0.06	-0.02	0.07	0.10	0.04
INFILT	10	-0.03	-0.08	0.25	-0.06	0.02	-0.06	-0.09	-0.04
INFILT	50	-0.13	-0.37	1.17	-0.26	0.09	-0.22	-0.42	-0.24
INTFW	-50	0.01	0.07	-0.06	0.06	-0.13	0.22	-0.02	0.02
INTFW	-10	0.00	0.00	0.00	0.01	-0.02	0.04	0.00	0.00
INTFW	10	0.00	0.00	-0.01	-0.01	0.02	-0.04	0.00	0.00
INTFW	50	-0.02	0.01	-0.03	-0.05	0.07	-0.19	0.01	-0.02
LZSN	-50	0.54	0.36	0.17	0.88	0.28	-0.49	1.93	0.60
LZSN	-10	0.08	0.07	-0.05	0.14	0.05	-0.09	0.29	0.09
LZSN	10	-0.08	-0.07	0.07	-0.13	-0.05	0.08	-0.25	-0.09
LZSN	50	-0.34	-0.32	0.41	-0.56	-0.25	0.32	-1.00	-0.38
KVARY	-50	-0.05	-0.13	0.38	-0.12	0.00	0.10	-0.28	-0.06
KVARY	-10	-0.01	-0.02	0.06	-0.02	0.00	0.01	-0.05	-0.01
KVARY	10	0.01	0.02	-0.05	0.02	0.00	-0.01	0.04	0.01
KVARY	50	0.05	0.11	-0.18	0.07	0.00	-0.01	0.20	0.05
CEPSC	-50	0.23	0.07	0.73	0.08	0.26	0.38	0.27	0.26
CEPSC	-10	0.04	0.01	0.09	0.01	0.04	0.07	0.04	0.04
CEPSC	10	-0.04	-0.01	-0.09	-0.01	-0.05	-0.06	-0.04	-0.04
CEPSC	50	-0.18	-0.05	-0.48	-0.07	-0.22	-0.24	-0.21	-0.20
LZETP	-50	1.28	0.32	4.49	1.16	0.29	2.16	3.06	0.68
LZETP	-10	0.25	0.06	0.85	0.23	0.06	0.39	0.62	0.27
LZETP	10	-0.24	-0.06	-0.82	-0.24	-0.06	-0.36	-0.59	-0.25
LZETP	50	-0.89	-0.23	-2.95	-0.94	-0.28	-1.12	-2.18	-0.97
UZSN	-50	0.83	0.53	1.26	0.55	0.28	1.81	1.60	0.92
UZSN	-10	0.13	0.09	0.17	0.09	0.03	0.26	0.29	0.14
UZSN	10	-0.12	-0.09	-0.14	-0.09	-0.03	-0.23	-0.27	-0.13
UZSN	50	-0.51	-0.39	-0.61	-0.42	-0.11	-0.94	-1.22	-0.55

HSPF - Water Quality Parameter Sensitivity Analysis

For the water quality sensitivity analysis, an initial base run was performed using precipitation data from water years 1999 through 2006, and model parameters established for 2001 conditions (see Section 4.5 for a complete explanation of selected model time periods). The three HSPF parameters impacting the model's water quality response (Table D.3) were increased and decreased by amounts that were consistent with the range of values for the parameter. FSTDEC (First Order Decay) was the parameter with the greatest influence on monthly geometric mean concentration, although MON-SQOLIM and WSQOP also showed significant potential to influence this value (Table D.4, Figures D.1, D.2, and D.3).

Table D.3 Base parameter values used to determine water quality model response.

Parameter	Description	Units	Base Value
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	0-1.1E+13
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	0-2.8
FSTDEC	In-stream First Order Decay Rate	1/day	5.0

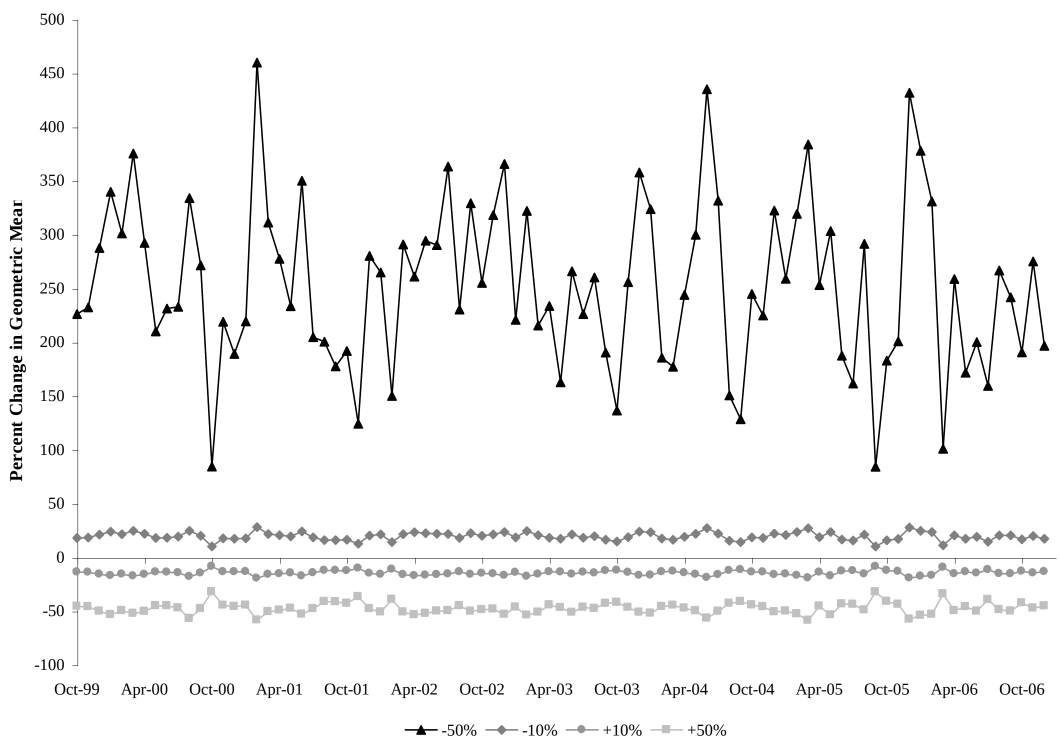

Figure D.1 Sensitivity analysis results from Bernards Creek (subwatershed 16), as affected by changes in FSTDEC.

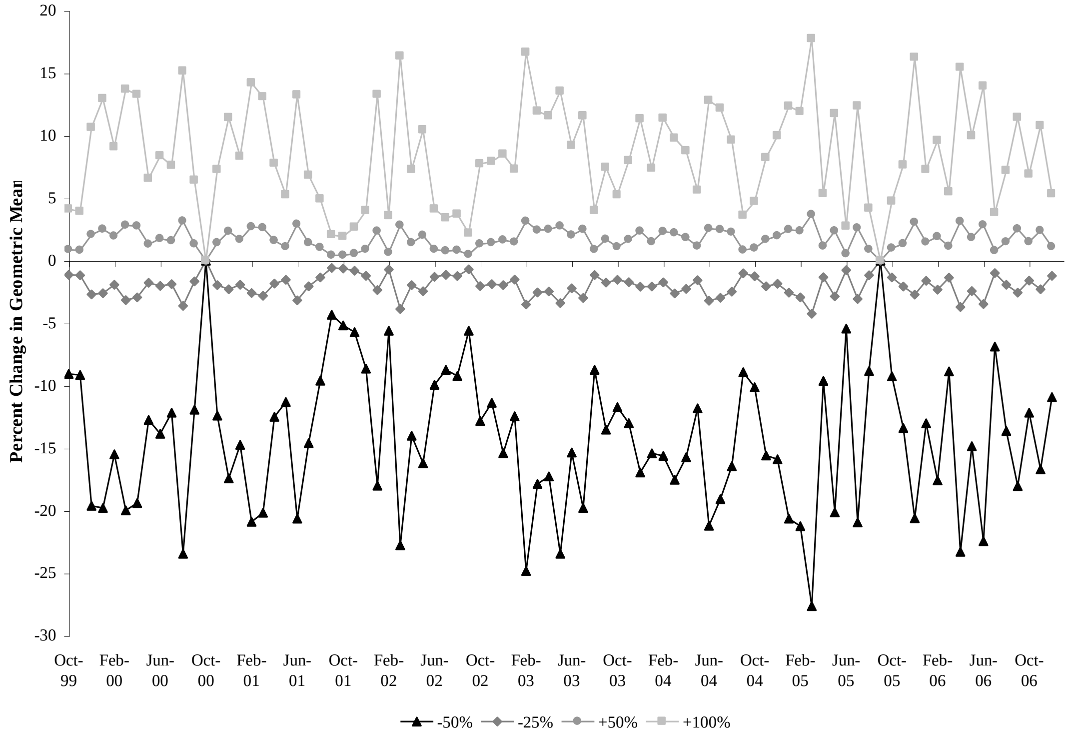

Figure D.2 Sensitivity analysis results from Bernards Creek (subwatershed 16), as affected by changes in MON-SQOLIM.

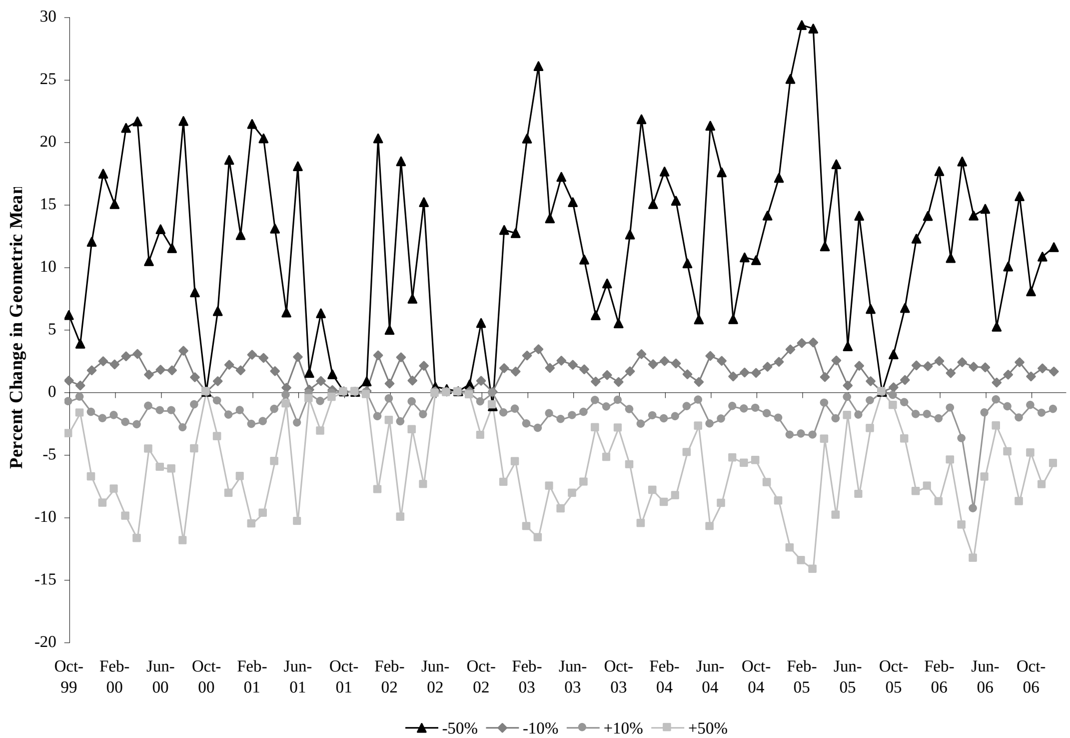

Figure D.3 Sensitivity analysis results from Bernards Creek (subwatershed 16), as affected by changes in WSQOP.

Table D.4 Percent change in average monthly *E. coli* geometric mean for the years 1999-2006 for Bernards Creek (subwatershed 16).

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly *E. coli* Geometric Mean for 1998-2003											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	290.68	336.70	313.30	262.19	215.63	286.76	260.28	269.65	228.77	227.42	249.40	335.66
FSTDEC	-10	21.81	24.36	23.16	21.39	19.29	21.82	19.38	20.99	18.56	18.55	18.83	23.05
FSTDEC	10	-15.95	-17.49	-16.90	-15.78	-14.74	-16.04	-14.44	-15.57	-13.96	-13.98	-14.00	-16.59
FSTDEC	50	-50.72	-53.62	-52.94	-50.28	-48.56	-51.22	-47.38	-50.55	-46.16	-46.08	-45.98	-51.72
SQOLIM	-50	-17.11	-22.13	-22.40	-16.55	-19.49	-18.63	-17.50	-17.29	-10.86	-11.46	-13.42	-16.89
SQOLIM	-10	-2.19	-3.02	-3.45	-2.45	-2.83	-2.81	-2.62	-2.59	-1.45	-1.71	-1.93	-2.16
SQOLIM	10	2.06	2.76	2.95	2.04	2.28	2.33	2.15	2.21	1.28	1.18	1.61	2.16
SQOLIM	50	10.69	14.41	14.86	10.01	11.31	11.25	10.31	10.32	5.84	6.43	8.00	11.01
WSQOP	-50	17.98	20.42	23.37	12.84	15.13	14.41	11.77	12.66	8.24	5.55	7.61	14.28
WSQOP	-10	2.51	2.88	3.21	1.68	2.12	2.00	1.75	1.96	1.22	0.85	1.17	2.06
WSQOP	10	-2.20	-2.55	-2.81	-1.76	-2.23	-1.77	-1.56	-1.74	-1.11	-0.77	-1.06	-1.82
WSQOP	50	-8.61	-10.47	-11.43	-6.41	-8.16	-7.24	-6.59	-7.20	-4.59	-3.29	-4.60	-7.64

In addition to analyzing the sensitivity of the model response to changes in water quality transport and die-off parameters, the response of the model to changes in land-based and direct loads was also analyzed. It is evident in Figure D.4 that the model predicts a linear relationship between increased fecal coliform concentrations in both land and direct applications, and total load reaching the stream. The magnitude of this relationship differs greatly between land applied and direct loadings. A 100% increase in the land applied loads results in an increase of 99% in total stream load, while a 100% increase in direct loads results in less than a 5% increase in total stream load. This demonstrates the model is more sensitive to changes in land-based load estimates and parameters. In contrast, the sensitivity analysis of geometric mean concentrations showed that direct loads and land based loads showed similar impacts (Figures D.5 and D.6).

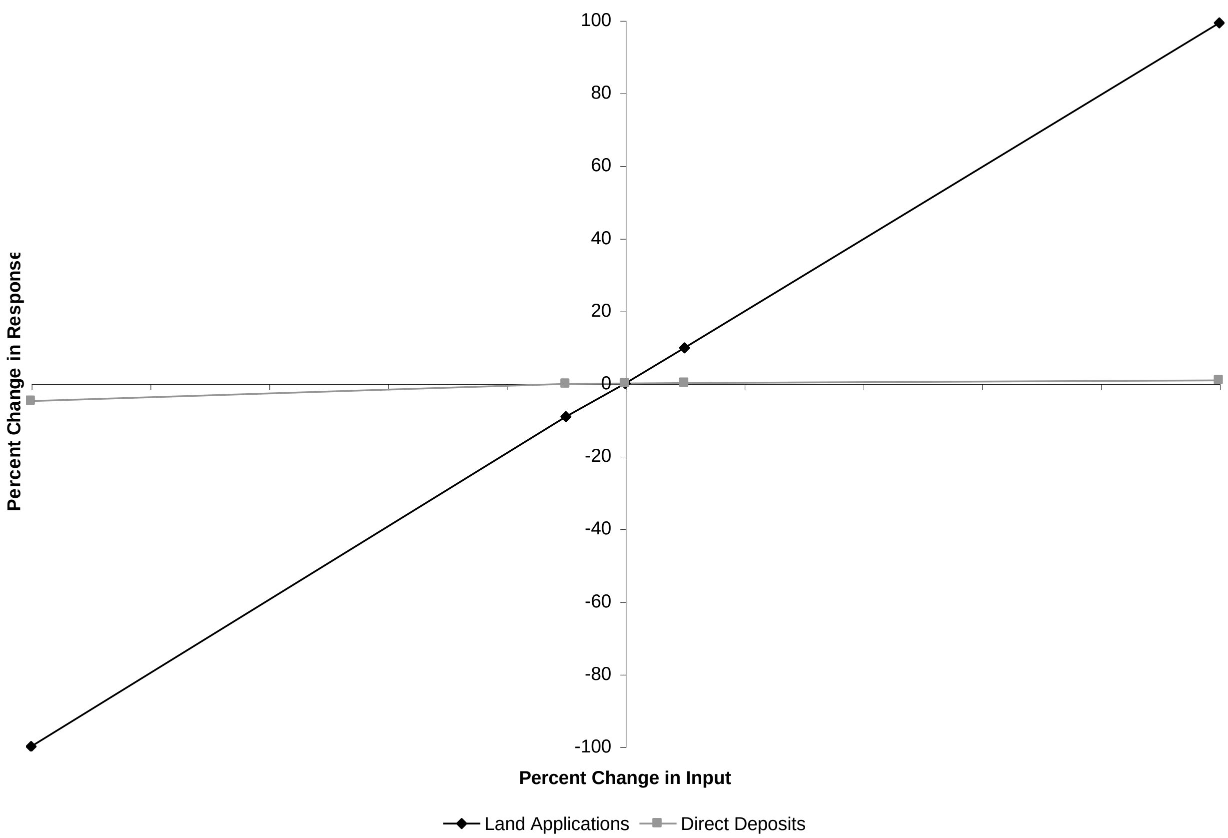

Figure D.4 Results of total loading sensitivity analysis for Bernards Creek (subwatershed 16).

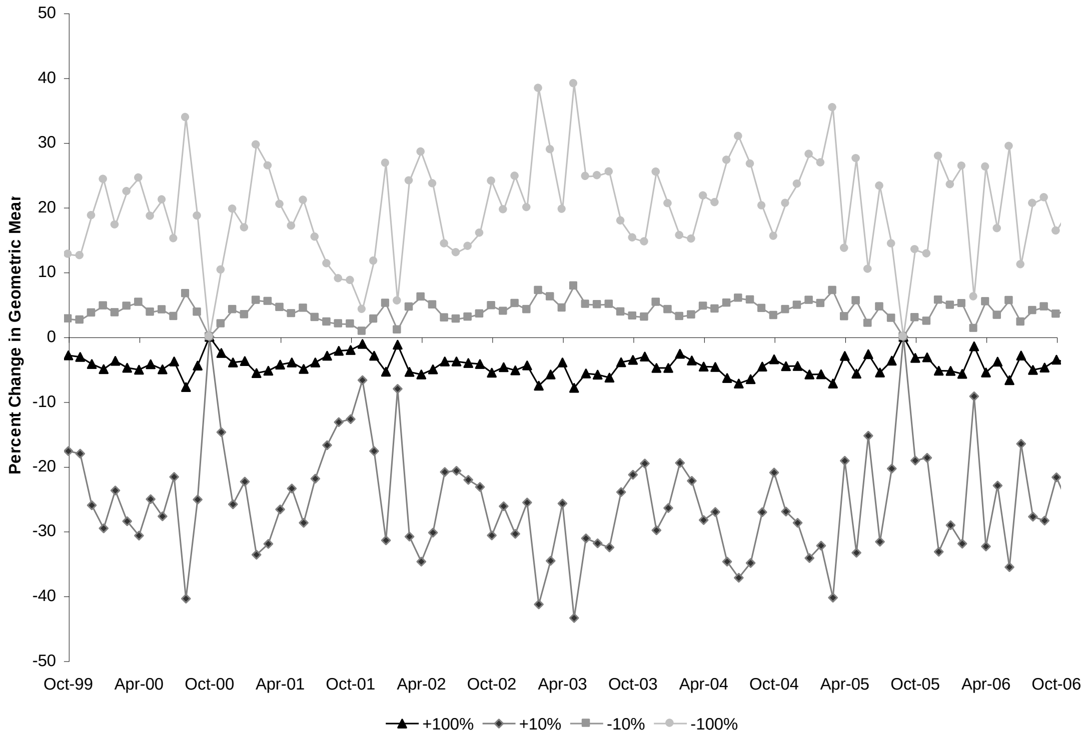

Figure D.5 Sensitivity analysis results from Bernards Creek (subwatershed 16), as affected by changes in land-based loadings.

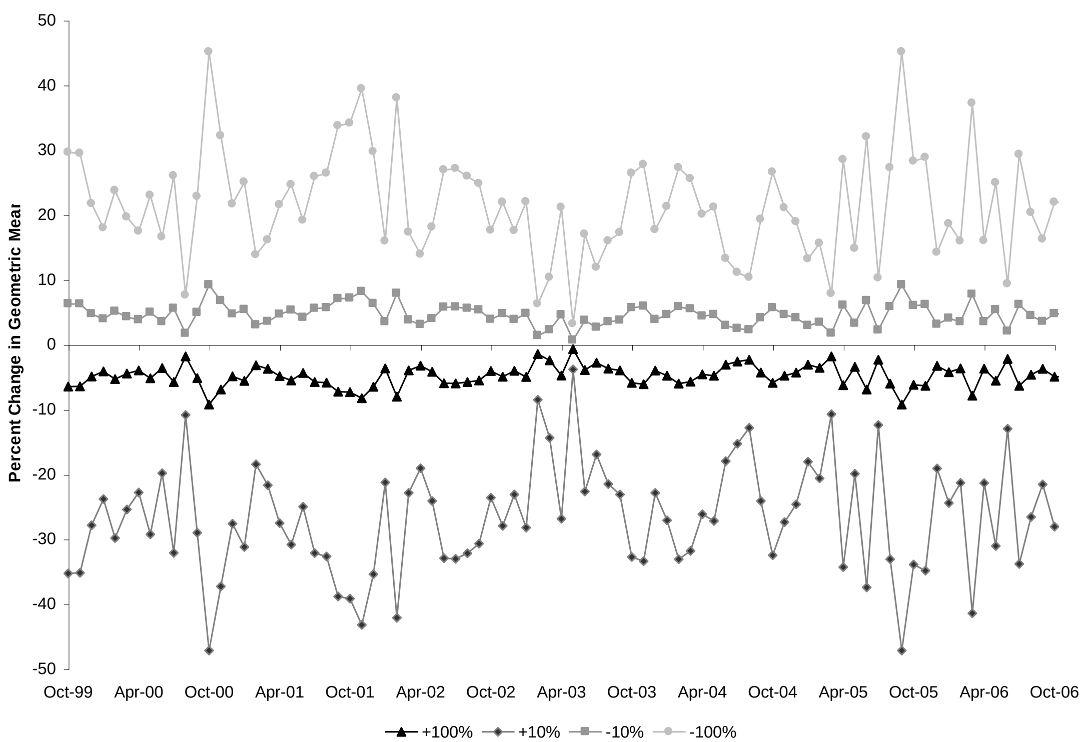

Figure D.6 Sensitivity analysis results from Bernards Creek (subwatershed 16), as affected by changes in direct nonpoint sources loadings.

APPENDIX E: CITY OF RICHMOND'S LONG TERM CONTROL PLAN (LTCP) MAP

Courtesy of the City of Richmond and Greeley & Hansen

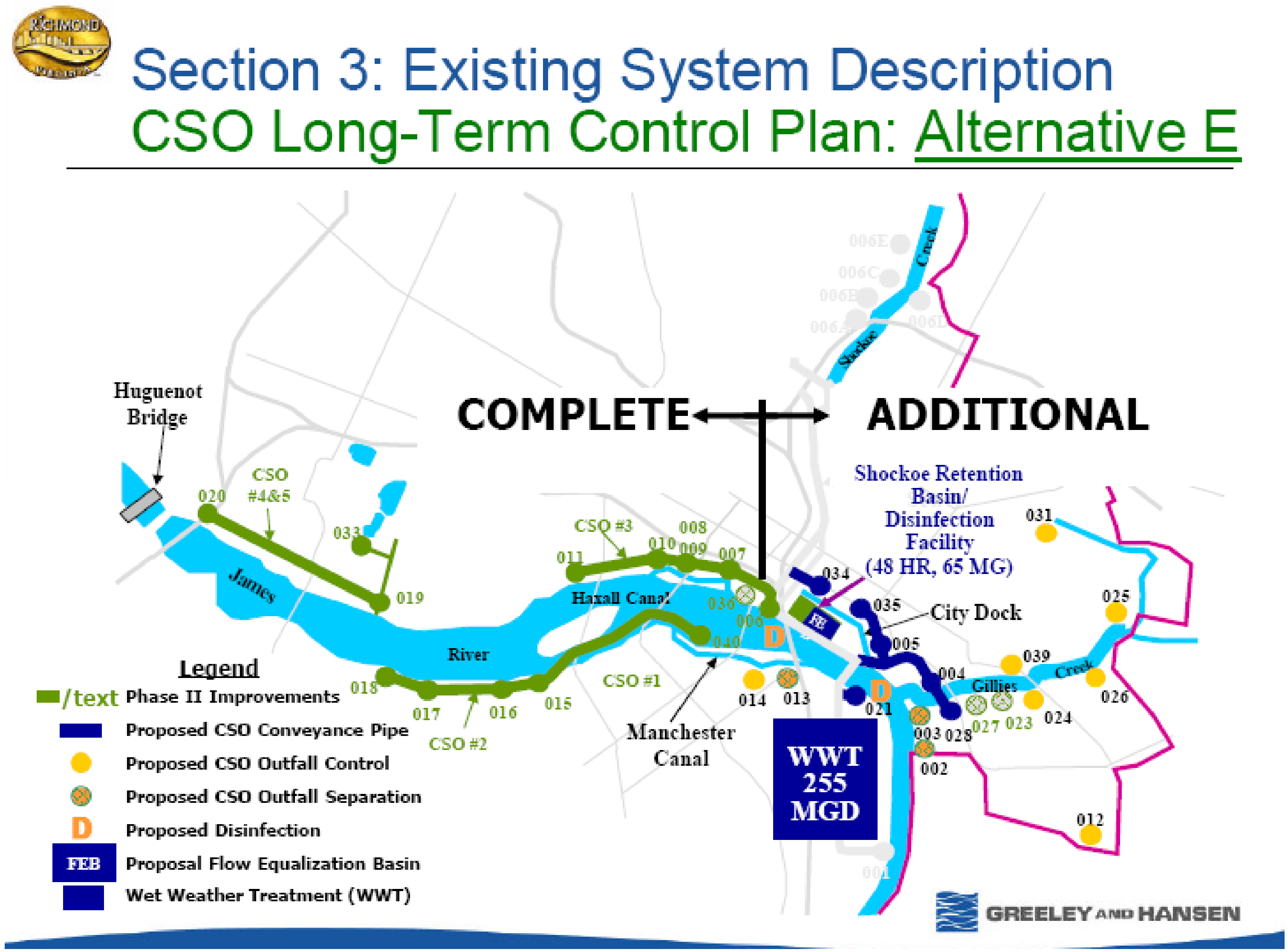

Figure E.1 A map of the City of Richmond's Long Term Control Plan - Alternative E (Greeley and Hansen, 2006).

APPENDIX F: TABLES EXTRACTED FROM THE CITY OF RICHMOND'S 2008 CSO REPORT

Table 2-1

Summary of Precipitation and Modeled CSO Occurrences for 2008
City of Richmond

Date			Rainfall (inches)	CSO (1)		Date			Rainfall (inches)	CSO (1)
1	10	2008	0.04	No CSO		7	4	2008	0.01	No CSO
1	11	2008	0.03	No CSO		7	5	2008	0.69	CSO Occured
1	13	2008	0.06	CSO Occured		7	6	2008	0.68	CSO Occured
1	17	2008	0.60	CSO Occured		7	8	2008	0.01	No CSO
1	19	2008	0.11	CSO Occured		7	9	2008	0.41	CSO Occured
1	22	2008	0.01	No CSO		7	14	2008	0.21	CSO Occured
1	29	2008	0.01	No CSO		7	19	2008	0.20	CSO Occured
1	30	2008	0.10	CSO Occured		7	23	2008	0.99	CSO Occured
2	1	2008	2.56	CSO Occured		7	27	2008	0.82	CSO Occured
2	12	2008	0.06	CSO Occured		7	29	2008	0.03	No CSO
2	13	2008	0.50	CSO Occured		8	15	2008	0.10	CSO Occured
2	17	2008	0.02	No CSO		8	26	2008	0.01	No CSO
2	18	2008	0.01	No CSO		8	27	2008	0.39	CSO Occured
2	20	2008	0.02	No CSO		8	28	2008	5.22	CSO Occured
2	22	2008	0.24	CSO Occured		8	31	2008	0.01	No CSO
3	4	2008	0.86	CSO Occured		9	5	2008	2.49	CSO Occured
3	7	2008	1.70	CSO Occured		9	9	2008	0.01	No CSO
3	15	2008	0.42	CSO Occured		9	10	2008	0.55	CSO Occured
3	19	2008	0.19	CSO Occured		9	12	2008	0.01	No CSO
3	22	2008	0.04	CSO Occured		9	16	2008	0.06	No CSO
3	29	2008	0.11	CSO Occured		9	25	2008	2.14	CSO Occured
3	30	2008	0.04	No CSO		9	27	2008	0.01	No CSO
3	31	2008	0.15	CSO Occured		9	28	2008	0.01	No CSO
4	1	2008	0.03	No CSO		9	30	2008	0.66	CSO Occured
4	3	2008	0.76	CSO Occured		10	17	2008	0.66	CSO Occured
4	4	2008	0.17	CSO Occured		10	25	2008	0.39	CSO Occured
4	5	2008	0.53	CSO Occured		10	27	2008	0.27	CSO Occured
4	12	2008	0.26	CSO Occured		11	4	2008	0.33	CSO Occured
4	20	2008	5.41	CSO Occured		11	5	2008	0.01	No CSO
4	26	2008	0.10	CSO Occured		11	6	2008	0.02	No CSO
4	28	2008	1.06	CSO Occured		11	8	2008	0.05	CSO Occured
5	8	2008	2.57	CSO Occured		11	12	2008	0.01	No CSO
5	10	2008	0.08	CSO Occured		11	13	2008	0.27	CSO Occured
5	11	2008	1.81	CSO Occured		11	14	2008	1.50	CSO Occured
5	12	2008	0.04	No CSO		11	15	2008	0.06	CSO Occured
5	15	2008	0.37	CSO Occured		11	24	2008	0.37	CSO Occured
5	18	2008	0.01	No CSO		11	30	2008	0.89	CSO Occured
5	20	2008	0.20	CSO Occured		12	6	2008	0.03	No CSO
5	27	2008	0.02	No CSO		12	10	2008	2.98	CSO Occured
6	1	2008	0.30	CSO Occured		12	16	2008	0.59	CSO Occured
6	3	2008	0.32	CSO Occured		12	19	2008	0.08	CSO Occured
6	14	2008	0.39	CSO Occured		12	21	2008	0.36	CSO Occured
6	16	2008	0.12	No CSO		12	24	2008	0.02	No CSO
6	19	2008	0.02	No CSO		12	27	2008	0.02	No CSO
6	21	2008	2.32	CSO Occured						
6	22	2008	0.04	No CSO						
6	29	2008	0.13	CSO Occured						

Total Precipitation: 49.57 **Total CSO occurrences:** 60

Table 2-2

Summary of Modeled CSO Frequency and Volume for 2008
City of Richmond, Virginina

		2008 OVERFLOW SUMMARY	
CSO Number	Basin Name	FREQUENCY	VOLUME (MG)
33	Shields Lake	4	1.61
19	Hampton-CO	0	0.00
19	Hampton-NY	7	60.37
20	McCloy	6	24.61
11	Park Hydro	8	10.93
10	Gambles Hill	2	0.51
9	6 th & 7th St.	0	0.00
7	Byrd	2	0.07
	SUBTOTAL		98.10
18	42nd St.	1	0.00
17	Reedy Cr.	0	0.00
16	Woodland	1	0.13
15	Canoe Run	5	38.46
40	CSO-1 Out/SSJRP		
	SUBTOTAL		38.59
6	Shockoe	59	3221.58
34	19th & Dock	44	84.29
	SUBTOTAL		3305.87
14	Stockton St.	22	61.95
13	Maury St.	22	4.06
21	Gordon Ave.	52	185.26
	SUBTOTAL		251.27
2	Orleans	28	6.86
3	Nicholson	29	4.74
4	Bloody Run	33	24.14
5	Peach St.	4	0.54
23	Old Ful St. Br.	0	0.00
24	Gillies & Varina	40	25.47
25	Briel & Gillies Cr.	33	22.51
26	Gov't Rd. & NSRR	33	7.45
27	New W'Burg Rd.	0	0.00
28	W'Burg Rd.	17	18.89
31	Oak'Wd Cem.	12	12.17
35	29th & Dock	4	0.24
39	Gov't Rd. & Gillies	41	33.51
	SUBTOTAL		156.52
12	Hilton St.	38	19.81

TOTAL CSOs (MG)	3870.16